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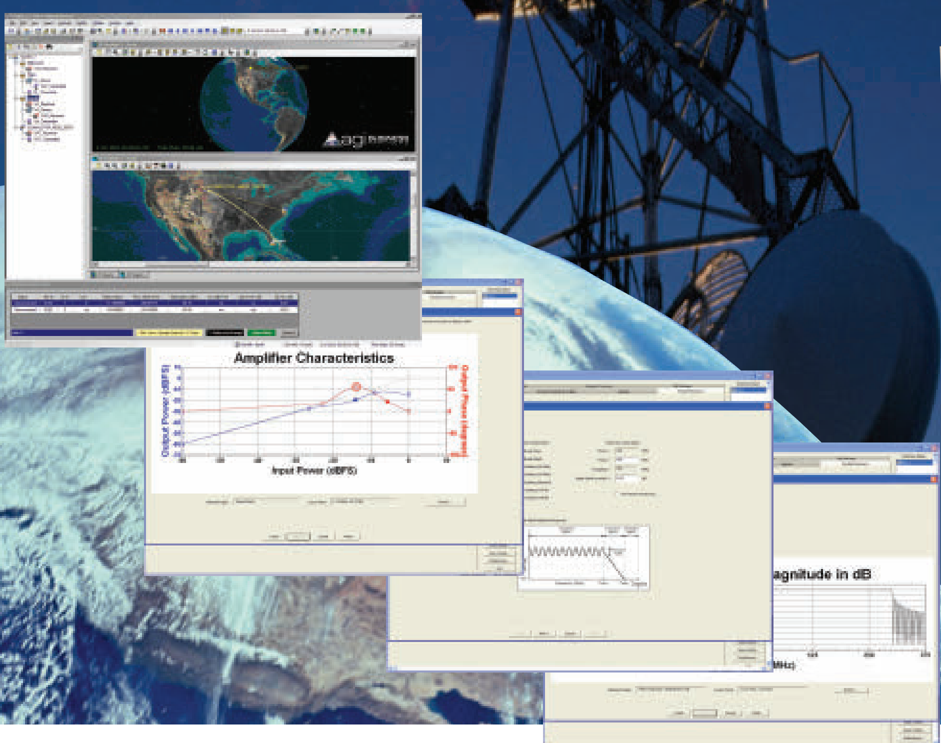

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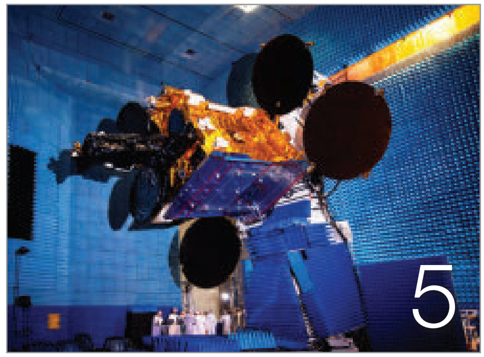

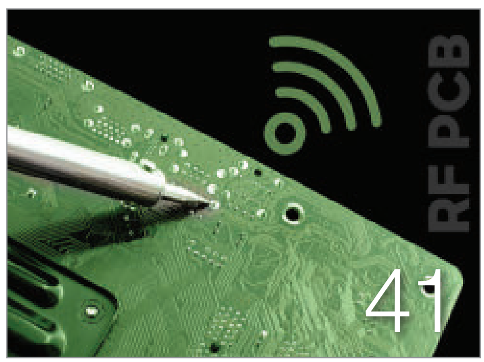

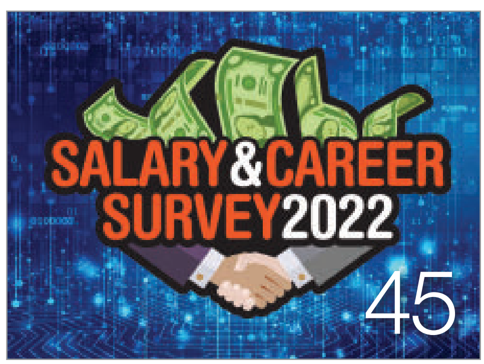

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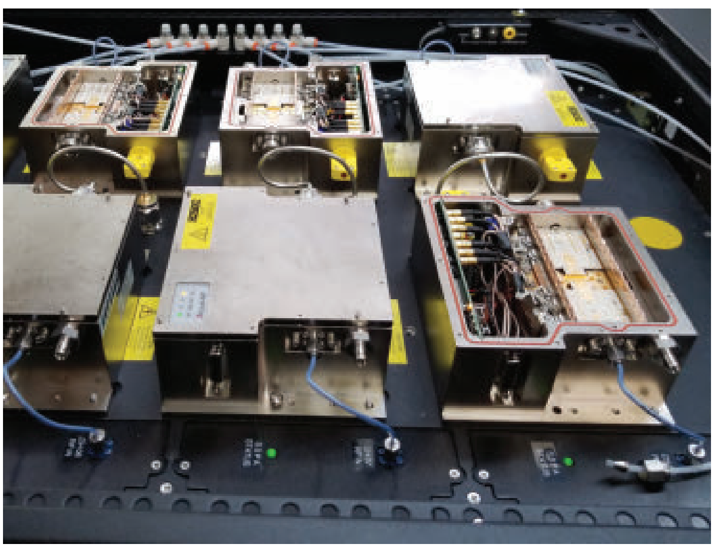

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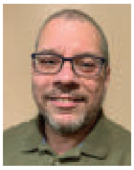

Editorial

DAVID MALINIAK | Editor

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How Much is a **Leader Worth?**

Results from our survey are favorable in terms of engineers' compensation, and they reveal the main driving force causing the uptick.

AS THE WORLD continues to shake off the calamitous effects of the COVID-19 pandemic, we see a wireless design-engineering community that's coming out of its slumber. An important indicator of the industry's get-up-and-go is attendance at trade shows and conferences. After nearly three years of lockdowns and travel restrictions, some of the recent industry conferences and exhibitions have been trending up.

Consider the recent 2022 edition of electronica: It was the first one in four years, and with 70,000 visitors, it came back strong with only a 14% drop in attendance from its record-setting 2018 event. Anecdotally, it also brought a sense of reawakening, a lot of positive energy, and an enthusiasm among attendees to get caught up on solutions they may have missed during the pandemic.

In parallel with our audience's revived interest in what's happening in the industry, we find ourselves with renewed interest in our audience. What's going on with you? How have you fared personally and professionally, and how do you feel about the future? To that end, the Design Engineering Group at Endeavor Business Media completed its annual survey of its audience on a variety of topics related to their professional lives.

One positive result of the pandemic, at least for electronic design engineers, has been a spike in compensation. A lot of that is because your employers are afraid of losing you and your valuable knowledge and experience. In fact, many of you have significant leverage in terms of salary and bonuses—and your employers know it. In 2020, as the pandemic took root, compensation seemed to take a hit, but that has turned around.

As you can see in this issue's piece by James Morra on our 2022 Salary and Career Survey, you're rather bullish on your expectations for compensation. Some 70% of survey respondents say that their compensation will have risen in 2022. Most also will see bonuses for their efforts this year. With that said, a third of respondents feel they're inadequately compensated. Yet, the survey reveals enough restlessness among you to keep employers anxious about maintaining their most valuable resource: its design and engineering talent.

Few forces drive society today more so than technology, and in the pantheon of technologies, wireless is king. You are the leaders of that movement, and you know darn well what that leadership is worth. Here's to a rising tide in 2023, one that will float all boats. ■

Microwaves&RF

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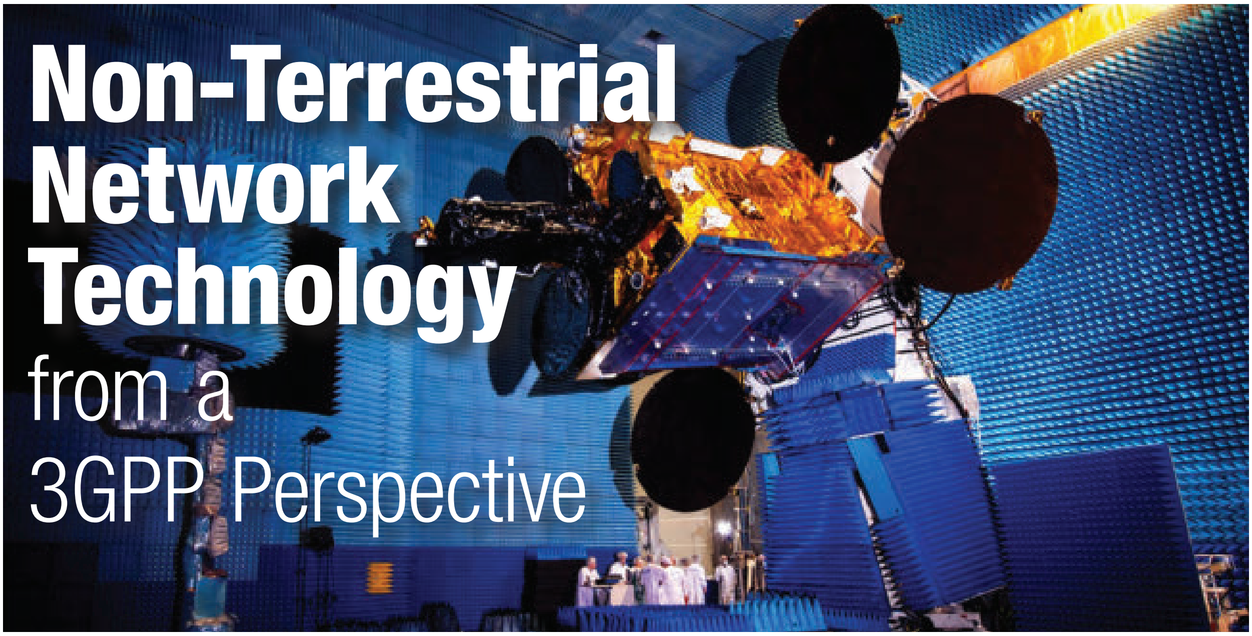
REINER STUHLFAUTH | Technology Manager, Rohde & Schwarz

Non-Terrestrial Network Technology from a 3GPP Perspective



In 5G, non-terrestrial networks represent a plethora of connection scenarios from satellite-based communications via airborne stations, considering situations like air-to-ground or flight control of UAVs.

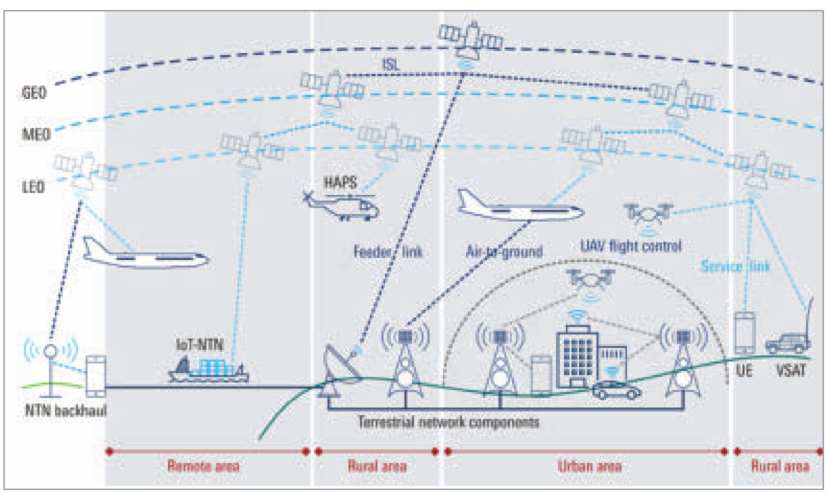
In 5G, non-terrestrial networks come in an array of connection scenarios, from satellite-based communications via airborne stations—e.g., air-to-ground or flight control of unmanned aerial vehicles (UAVs). This article gives a concise technology overview of the different network variations.

These include various satellite-based connectivity scenarios in which satellites differ in flying altitude and coverage area. To incorporate non-terrestrial networks (NTNs), 3GPP launched a Release 15 study [TR 38.811] on channel models and deployment scenarios. After completing this study, 3GPP followed up with a Release 16 study [TR 38.821] on solutions for adapting 5G NR to support NTNs. The main objective of this study is to identify a feature set that enables NTNs within the 5G system while minimizing the impact on the existing 5G system.

Why foster NTN communications? Answer: To fulfill the need for ubiquitous connectivity on a global scale. According to market statistics by industrial organizations such as GSMA, in 2020, wireless communications technologies covered more than 80% of the world's population but less than 40% of the Earth's land mass. NTN satellite-based communications can tackle this aspect and focus on worldwide ubiquitous coverage, even in maritime, remote, and polar areas *(Fig. 1)*.

Initial 5G NTN deployments will focus on ubiquitous connectivity and coverage, separating the technology into two facets: NR-NTN and IoT-NTN:

- NR-NTN can be thought of as the enhanced mobile broadband (eMBB) part of 5G enabling satellite-based connectivity, mainly focusing on coverage and outdoor applications.
- IoT-NTN is an extension of IoT technologies such as NB-IoT, LTE-



1. This image provides a general overview showing connectivity of non-terrestrial networks.
Images courtesy Rohde & Schwarz

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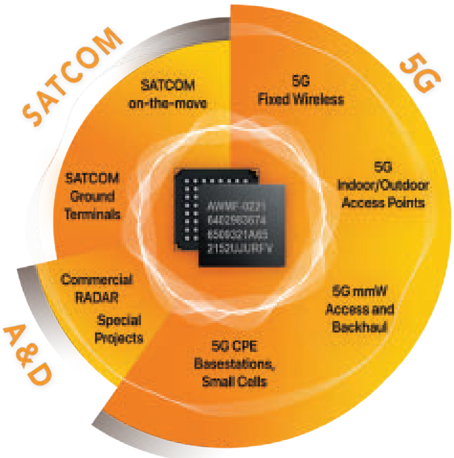

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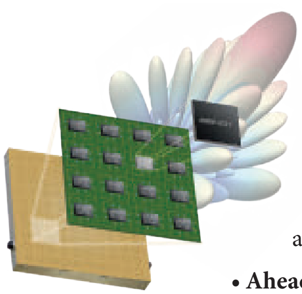

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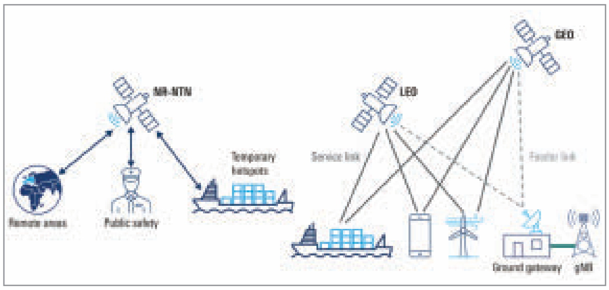
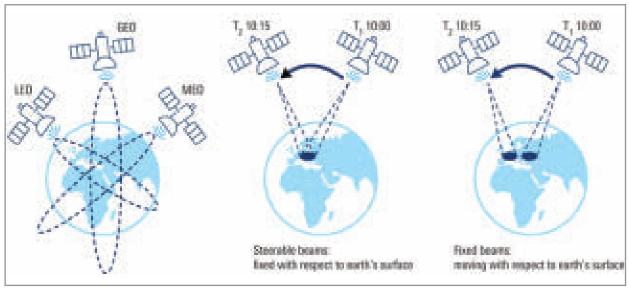


2. Here's a glimpse of how NR-NTNs incorporate non-terrestrial communications within the 5G system. NR-NTN use cases follow 5G eMBB services.



3. For NTN satellite beamforming, two methods are in discussion—moving beams (left) or fixed beams with respect to earth surface (right).

M, or 5G RedCap (also known as 5G NR-Light) in long-term satellite connectivity scenarios.

The latter assumes a best-effort QoS approach with very tolerant requirements concerning delays and data rates. In terms of expected data rates, NTN 5G can't compete with terrestrial 5G, so 5G NTN will complement terrestrial 5G systems and provide connectivity in underserved regions.

NTN Use Cases

With the current evolution of NTNs, two major directions became apparent:

- First, 5G NR enhancements incorporate non-terrestrial communications within the 5G system. NR-NTN use cases follow 5G eMBB services. The technology is described as NR-NTN *(Fig. 2)*.
- Second, the Internet of Things (IoT), or massive machine-type communications (mMTC), is extended by non-terrestrial connectivity, described as IoT-NTN, which differs from NR-NTN by dint of overall lower complexity. The radio link continues with the adaptation of NB-IoT or enhanced machine-type communications (eMTC) for NTN connections, but with reduced device and satellite complexity.

Another characteristic of IoT-NTN is the lack of QoS support. IoT-NTN communications will be established with a best-effort approach, like latency-tolerant applications, but compared to NR-NTN, energy efficiency and power saving play a pivotal role. The [TR 36.763] study proposes both radio-access technologies (RATs)—eMTC and NB-IoT—with equal priority. And, in the first potential deployments, evolved packet-core (EPC) connectivity is the core network in charge. 5G Core may follow at a later deployment phase.

Rel. 17 prioritizes standalone deployment, applying transparent bent-pipe satellite architecture and assuming the user equipment (UE) possesses GNSS capabilities (not simultaneous operation) to pre-compensate time and frequency.[3]

The 3GPP study on next-generation access technology scenarios and requirements found multiple use cases ranging from indoor hotspots to satellite-based 5G system extensions [TR 38.913]. Satellite-based communications aren't new to the ecosystem, and services can be clustered into broadcast satellite services (BSS), fixed satellite services (FSS), and mobile satellite services (MSS).[4]

Fixed satellite services

FSS provides internet and connectivity services to stationary UE, such as very-small-aperture terminals (VSATs). From a business-case perspective, such services have an objective not unlike fixed-line connectivity. The advantage of FSS is its wide coverage and capability to provide connectivity services to underserved or remote areas. An FSS service subset also could be the future deployment of backhaul connectivity of terrestrial 5G radio networks.

Broadcast satellite services

These services correspond to the well-known satellite TV broadcasts (such as DVB-S2). With 3GPP, it's possible to use such systems to broadcast information to either all or a subset of UEs.

Target applications include services like updating software or providing information to regions or UE groups. Another business model includes outsourcing of traffic. If it's relevant to multiple UEs spread over a large coverage area, such broadcast-based systems improve overall system efficiency.

Mobile satellite services

These have the same use cases as the cellular terrestrial networks, but with the advantages of wider coverage and ubiquitous connectivity and disadvantages of potentially lower data rates, longer latency, and targeting for outdoor operations. NTN services complement terrestrial 5G systems. It prioritizes worldwide connectivity and basic service provisioning in a wide coverage area instead of single-user high data rates.

3GPP NTN focuses on more than underserved area coverage. At a higher level, these four use cases are categorized as follows [TR 22.822]:

- **Service continuity** provides RAT coverage where it's unfeasible through terrestrial networks such as in maritime or remote areas. It supports service continuity between land-based 5G access and satellite-based access networks owned by the same operator or by operator agreements.

- **Service ubiquity** is motivated by mission-critical communications (MCX) and aims at permanent system availability. This is particularly evident for public protection disaster relief (PPDR) use cases leading to outage or destruction of terrestrial network architectures. System availability can be resumed and obtained in a short time using NTN connections.
- **Service scalability** follows the general aspect of traffic-management strategies. Enhancements of traffic steering like the offloading of traffic from terrestrial to non-terrestrial communications provide better system efficiency, especially when considering the wide NTN, next-generation Node B (gNB) coverage range.
- **5G system backhaul services** represent situations where end-user devices are still connected to terrestrial RATs, but the NTN connection serves as a backhaul connection to the core network.

NTN Spectrum Aspects

The most relevant communications aspect is the available frequency spectrum. As it's extremely unlikely that satellites are restricted to one country or region, an international harmonization of frequencies applied to satellite communications is essential. Organizations like the ITU support such coordination initiatives.

Currently, several frequency ranges are being discussed within 3GPP for NTN. Some are in the FR1 legacy spectrum, and some beyond 10 GHz and FR2. The current FR1 bands discussed for NTN are:

- The S-band frequencies from 1,980 to 2,010 MHz in uplink (UL) direction and from 2,170 to 2,200 MHz in downlink (DL) direction (Band n256).
- The L-band frequencies from 1,525 to 1,559 MHz DL together with 1,626.5 to 1,660.5 MHz for the UL (Band n255).[1]

These frequency ranges have lower path attenuation, and they're already used in legacy communications. Thus, components are available now, but the bands are very crowded, and the usable bandwidth is restricted. Current maximum bandwidth is 20 MHz with up to 40-MHz overall bandwidth envisaged in the future [TR 38.811].

As far as long-term NTN spectrum use is concerned, 3GPP is discussing NR-NTN above 10 GHz. The Ka-band is the highest-priority band with uplinks between 17.7 and 20.2 GHz and downlinks between 27.5 and 30 GHz, based on ITU information regarding satellite communications frequency use.[2] Among current FR2 challenges, one is that some of the discussed bands fall into the spectrum gap between FR1 and FR2 and that NTN frequencies will use FDD duplex mode due to the long roundtrip time.

Like terrestrial communications, coexistence aspects also are relevant for NTN. This is due to RF layer interference leveraged by two facts resulting from the NTN introduction: The cell or beam coverage overranges country and terrestrial cell borders, and the spectrum location either overlaps or is adjacent to existing 5G bands. For such reasons, 3GPP started a study initiative to further investigate coexistence aspects [TR 38.863].

NTN Architecture Aspects

The following architectures are relevant for current and future NTN and satellite constellations:

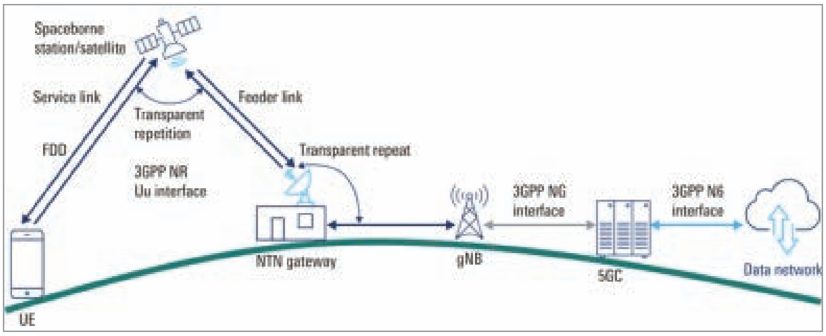
- **Low-Earth-orbit (LEO)** satellites with an altitude between 500 and 2000 km have a shorter round-trip time (RTT), which is typically less than 30 ms. The size of a LEO satellite also is assumed to be small, typically <1-meter perimeter or even in the range of a dozen centimeters (nanosatellites), with the weight below 500 kg. The assumption is that NTN uses a beamforming mechanism at the satellite station. The typical beam footprint of a LEO satellite ranges between 100 and 1000 km.
- **Medium-Earth-orbit (MEO)** satellites travel at a velocity of about 13,800 km/h and have an orbital period of around six to 12 hours. The beam footprint is like that of LEO constellations.
- **Geostationary-Earth-orbit (GEO)** satellites operate above the equator at an altitude of 35,786 km, resulting in a notional station keeping its position fixed in terms of elevation and azimuth angle with respect to a given Earth point. The beam-footprint sizes range from about 200 km for narrow beams up to 4,000 km in the case of large beam sizes. Due to the larger distance, the RTT of a GEO satellite is about 544 ms.
- **High-altitude platform systems (HAPS)** cover all airborne objects such as airplanes, balloons, helicopters, and drones (UAVs). They operate very flexibly at altitudes from several hundred meters up to about 15 km and have a beam footprint with diameters of just a few kilometers up to 100 km on average. Due to the shorter distance, the RTT isn't unlike that of terrestrial networks. Two satellite beamforming methods are discussed: The beam footprint with respect to earth is either static or moving. As shown in *Figure 3*, there are *steerable beams* and *Earth fixed beams*.

A general characteristic of NTN connections is the addressability of the satellite as we may observe a birth and death situation that's dependent on the elevation angle. In addition, the 5G system extension to incorporate non-terrestrial networks includes adapting to existing 5G system architectures. Especially on the radio access network (RAN), the change from a terrestrial base station to an airborne or spaceborne satellite access station results in some amendments.

NTN architectures need radio access from the terrestrial terminal or UE to the satellite, which is referred to as the

service link, and the satellite needs to be connected to a terrestrial gateway, referred to as the feeder link. LEO and GEO satellite constellations have a known or predictable trajectory, which facilitates the routing of the connection to the ground station.

Targeting an NTN-capable RAN deployment, two possible architecture options are discussed within 3GPP: transparent mode and regenerative mode. Release 17 deals primarily with the transparent-mode architecture.



4. Shown is a symbolic representation of a transparent NTN NG-RAN architecture. In real-world applications, there are possible permutations.

Transparent NTN NG-RAN Architecture

This architecture behaves like a repeater in space (sometimes referred to as the "bent pipe approach") and follows the principle of "what goes up must come down." The major aspect is the disaggregation of the legacy term "base station" into the components of satellite, ground gateway, and terrestrial gNB functions. The satellite functions implement RF filtering, frequency conversion, RF amplification, RF transmission, and reception in uplink as well as downlink direction.

The pivotal characteristic is that the waveform is repeated between the service and feeder link by an unchanged payload. A carrier frequency change is probably applied to avoid interference between the service and feeder links.

This architecture is independent of the radio waveform, so any amendments here don't require changes in the spaceborne station. Disadvantages include noise amplification, as the satellite may not perform any channel equalization or noise cancellation; the vulnerability against jamming attacks; the longer overall RTT as two satellite-earth links are involved; and the lack of inter-satellite link (ISL) connections for traffic steering.

The termination of the 5G NR air interface with respect to the protocol anchor is in the terrestrial gNB function. The gateway function has no explicit task with respect to 5G NR but, of course, an important task with respect to satellite flight control and other tasks. It's probably a parabolic antenna or antenna array with beamforming capabilities to steer the feeder link heading toward the satellite station. The architecture shown in *Figure 4* is symbolic—certain deviations are possible. For example, the gateway and the gNB can be incorporated into the same hardware cabinet or the gNB functions are offered to several satellites. Conversely, a satellite is only connected to a single gNB to clarify the protocol termination point.

The connection between the UE and the terrestrial gNB includes service and the feeder link, but also several ISLs in between are possible in future extensions. [TR 38.821] states that the regenerative payload is required for first ISL implementations.

Future NTN deployments will include regenerative-mode architectures. The major difference to the transparent payload architecture is that gNB functions are incorporated into the satellite itself for faster scheduling decisions and shorter RTT. The regenerative architecture model raises satellite hardware complexity and computing power and may incorporate multi-access edge-computing (MEC) functionalities to reduce the RTT.

NTN RF Aspects

5G enhancements starting with Release 17 will adapt 5G NR to allow for non-terrestrial network communications. This chapter deals with RF propagation aspects and the resulting challenges, with focus on non-terrestrial propagation aspects compared to well-known channel models or fading profiles in terrestrial propagation conditions.

The great distance between terrestrial end-users and spaceborne stations impacts the link budget by imposing high path attenuation. In addition, this huge distance is responsible for the large time delay or RTT, which also depends on the time and elevation angle.

A paradigm change is afoot: Compared to terrestrial networks, where the term "base station" indicates its stationary nature, satellites travel at a certain velocity, causing carrier-frequency deviation (Doppler shift). Ionospheric radio-wave propagation is responsible for waveform polarization rotation, known as Faraday rotation.

NTN channel modeling

The channel between the TX and RX entity is affected by certain degradations, such as interferences and fading. Large-scale fading mainly depends on the distance between TX and RX and the propagation of the radio wave between them. Small-scale fading is influenced by multipath propagation and Doppler shift of the carrier frequency. It depends on signal bandwidth, relative velocity, scattering, and reflection environments.

With NTN links, there's obstructed and unobstructed propagation. The unobstructed link benefits from a line-of-sight (LOS) dominance in the scattering profile that shows no rich scattering environment, while obstructed links assume

nearby scatterers. Note that NTN focuses on outdoor connectivity.

Some marginal differences exist between modeling of terrestrial channels and modeling of NTNs. In the latter case, modeling emulates LOS scenarios with multipath propagation resulting from nearby objects. The angular spread seen by the satellite is almost zero, whereas in terrestrial scenarios, it covers a certain angular range.

Thus, a major difference is that the satellite signal propagation is primarily homogenous except for nearby scattering. 3GPP wants to combine terrestrial fading models [TR 38.901] with satellite channels in a hybrid conceptual architecture.

Path attenuation

The long distance between the UE and the satellite will lead to high path attenuation. 3GPP has discussed several link budgets and carried out studies with diverse parameters and simulation results, such as shown in [TR 36.763] or [TR 38.811]. As antenna technology evolves, the objective is to tackle the path loss with highly directive antennas providing high antenna gain.

The composite path loss is based on the following components: basic path loss (mainly as free-space path loss, or FSPL), attenuation due to atmospheric gases, attenuation due to atmospheric scintillation, and building-entry path loss. Typical assumptions are FSPL values of –160 dB (LEO) or –190 dB (GEO), and it's assumed that the UE RX sensitivity will be lower compared to terrestrial networks.

Round-Trip Time and Differential Time Delay

One of the challenges of NR-NTN's low-latency communications is the RTT or long latency due to the large distance between the terrestrial UE and the satellite. Typical one-way latency values range from 30 to 40 ms in LEO constellations and up to 544 ms in GEO constellations.

A detailed analysis of the RTT and latency aspects identifies the following two challenges:

- Differential delay between the NTN gNB and all UEs in a beam-footprint coverage area due to the nature of the elliptical shape and the elevation angle impact.
- Time-variant latency and varying RTT during the entire connection period due to the nature of an elliptical flight orbit and the changing distance between the UE and the satellite.

The first aspect considers the elliptical beam footprint, but the size of the ellipse depends on the elevation angle. The satellite thus experiences different propagation times among the UEs within the beam footprint.

When considering the second aspect, the UE experiences RTT behavior that varies over time due to the nature of the satellite's orbital trajectory. When the satellite appears at the horizon above the minimum elevation angle, the RTT is largest as the distance between the UE gNB is longest. This impacts the buffer management of the MAC layer and HARQ operation.

Doppler frequency shift

One of the most serious challenges in realizing NTN connections with good end-user QoE is carrier-frequency deviation (Doppler shift). The paradigm change of a moving base station or satellite in combination with an optional moving UE causes a time-variant Doppler shift across the connection time. It depends on the relative velocity between UE and satellite, the carrier frequency, and the angle between the velocity vector and the direction of signal propagation.

Faraday rotation in NTN and polarization aspects

Faraday rotation is visible due to the structure of the atmosphere, indicated by the total amount of electrons. Faraday rotation is introduced to describe the rotation of the polarization resulting from interaction of the electromagnetic wave with the ionized medium in the Earth's magnetic field along the path [TR 38.811].

A possible countermeasure is the use of circular polarization methods. The drawback is that this would either require the UE to apply the same circular polarization to achieve a perfect match or tolerate and accept 3-dB polarization loss in addition to the FSPL.

Summary

3GPP states that with 5G NTN, satellite-based communications should be made possible, but with the lowest impact on 5G. Only technically necessary adaptations will be made.

In the long term, on the path toward 6G, we will leave the cellular behavior of networks behind.[4] Therefore, 6G will consist of dynamic, multiple, and intelligent nodes with onboard computing power and multi-access edge-computing functionality, interconnected and moving relative to each other. The three terms "interworking," "integration," and "unification" describe the evolution path from legacy technologies in the satellite and cellular world via 5G NTN and heading up to 6G.

New research areas will be the evolution toward organic networks with cell birth and death behavior, vagabonding network components, and intelligent traffic management. The incorporation of NTN into the 5G system with Release 17 is the advent of a new technology evolution fostering and driving the worldwide proliferation of wireless communications systems. Rohde & Schwarz is accompanying these technology evolutions with expertise in test and measurement and in satellite connectivity. ■

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– Peter Schubert, Professor of Electrical and Computer Engineering, IUPUI

Design Feature

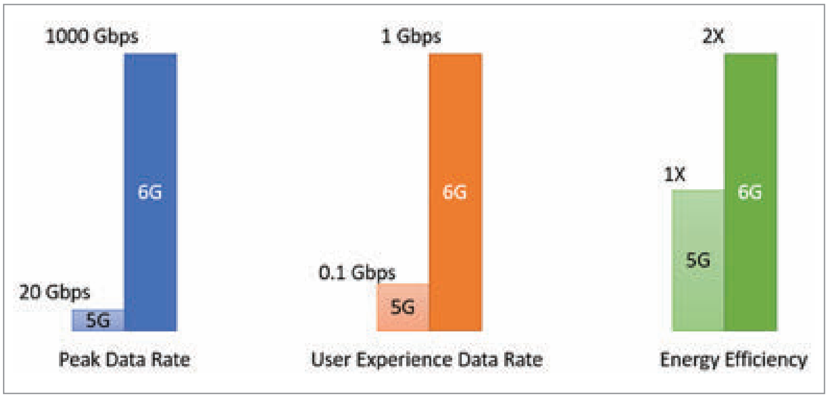
ALEJANDRO BURITICA | RF Product Manager, Tektronix

Improve the Reliability of 6G Designs with High-Fidelity Test Beds

Analysis tools that operate on both software-modeled and simulated data, as well as actual measured data from high-bandwidth test equipment, will boost reliability of 6G designs.

The wireless communications industry continues its strong deployment of 5G cellular networks and services to enable greater user data throughput, lower latency, and widespread IoT coverage. While engineers are busy tackling the challenges of commercial 5G implementation, many industry researchers are ramping up their efforts to conceive the next generation of wireless communications: 6G.

At this early stage, the use of easily reconfigurable, high-fidelity, and wide baseband signal-generation and analysis tools give researchers the ability to reliably recreate test scenarios to validate the expected performance indicators.



1. KPIs for 6G are expected to be more challenging than for 5G cellular communications. *Tektronix*

Lofty Aspirations for 6G KPIs Present T&M Challenges

Industry experts have several ideas of what 6G should accomplish in the next decade when it's solidly deployed, including data rates in the terabits-per-second range, lower-power communications, and joint communications and sensing. Some of the key performance indicators (KPIs) targeted by industry experts for 6G networks *(Fig. 1)* are lofty aspirations that pose great engineering challenges and call for a gradual and iterative design process.

Consider, for example, that 6G plans to use channels with 8 GHz or more of instantaneous bandwidth around sub-terahertz bands from 140 to 300 GHz. At these higher frequencies, the much shorter wavelengths push against semiconductor physics and system-level mechanical dimensions, which can introduce considerable variations in wireless performance.

Furthermore, operating in these large channels requires wider baseband capabilities, faster signal processing, and greater integration of the transceiver and radio chain. A high level of radio-device integration demands exhaustive simulations because it would be very difficult, if not impossible, to directly measure, test, and optimize the individual subsystems and components.

Following the development path of 5G devices in the mmWave range, the engineering of integrated 6G systems will lean on radiated, over-the-air (OTA) measurements. Here, researchers present very wide baseband signals to the device under test (DUT), and then determine the RF performance of their designs by analyzing the demodulated baseband signals at the end of the OTA link.

A hardware-enabled prototyping 6G test bed capable of generating and analyzing wide signals requires test and measurement equipment with very fast and high-fidelity analog-to-digital converters (ADCs) and digital-to-analog converters (DACs). This will minimize measurement uncertainty, provide equalized flatness across wide channels, and simplify the execution of automated test sequences for system characterization *(Fig. 2)*.

Research and development test beds need flexibility to address many frequency bands, various modulation bandwidths, and new types of waveforms. Such test setups also need to scale to many channels to investigate multiple-input, multiple-output (MIMO) techniques.

High-performance arbitrary waveform generators (AWGs) produce high-bandwidth test signals at baseband, taking advantage of very fast sampling rates. These high rates enable low residual error-vector magnitude (EVM) at lower intermediate frequencies thanks to the oversampling processing gain.

Using high-spectral purity local oscillators and D-band (110 to 170 GHz) and

G-band (140 to 220 GHz) upconverters to generate sub-terahertz signals with very wide bandwidths, the test bed then translates this wideband signal closer to the sub-terahertz range. It brings the 6G DUT nearer to its operating frequency and enables the filtering of the undesired image product.

Analyzing 6G Signal Quality

To analyze the signal quality out of the 6G DUT, the system first downconverts from sub-terahertz frequencies to an intermediate frequency. Then, taking advantage of high-bandwidth, multichannel, real-time oscilloscopes, the system acquires the waveforms and passes the IQ samples to the test computer for demodulation and post-processing.

The test system provides spectral and modulation measurement results, such as occupied bandwidth, modulation constellation, and EVM. Researchers can scale the number of channels for MIMO research thanks to the synchronization and multichannel capabilities of the AWGs and oscilloscopes.

Flexible Test Beds Accelerate Modeling, Simulation, and System Design

At the 2022 International Microwave Symposium, Tektronix let researchers from the technology research institute CEA-Leti (Laboratoire d'électronique des technologies de l'information), Grenoble, France, create a test bed to demonstrate their latest energy-efficient, D-band, wireless receive (RX) and transmit (TX) integrated circuits (ICs) fabricated in 45-nm CMOS RFSOI technology.

Utilizing modeling, simulation, and signal-processing software, the researchers created baseband waveforms using 16-QAM modulation mapped to four channels of 2.16 GHz each. With the Tektronix AWG70000 arbitrary waveform generator, researchers were able to generate baseband signals with bandwidths greater than 8 GHz, which were then upconverted to an intermediate frequency of 61.5 GHz.

The TX IC performed channel bonding and executed a final upconversion to 147.96 GHz, and then fed the signal to an electromagnetic lens antenna, which in turn generated a narrow beam. Positioned about 20 cm away, the RX IC subsequently picked up the radiated signal, downconverted it to an intermediate signal, and passed it to a low-noise amplifier. This IF signal was fed into a Tektronix DPO70000SX oscilloscope, which digitized the wideband signal and passed the IQ samples to the application software for demodulation.

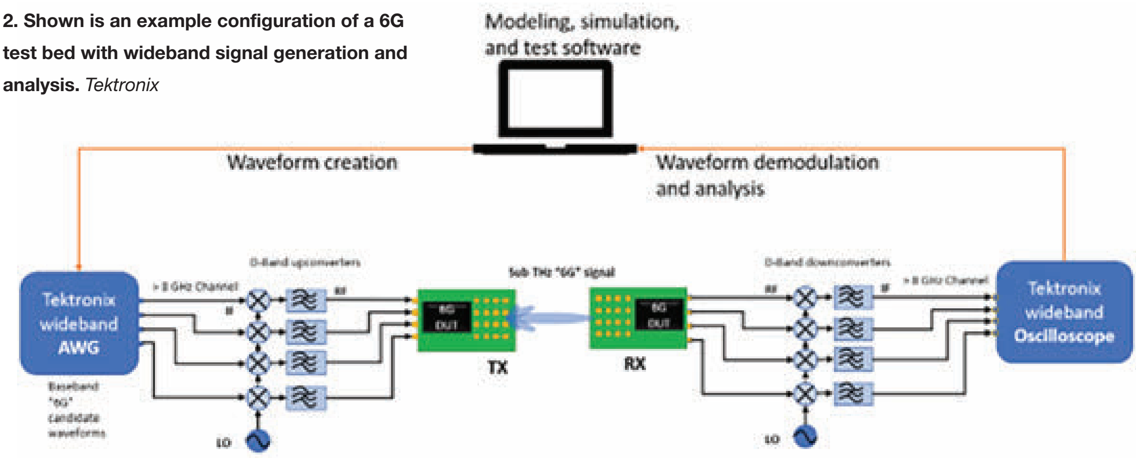
The researchers achieved a very encouraging data rate of 56.32 Gb/s with a competitive energy consumption (RX+TX) of 18 pJ/bit, including the generation circuitry for the local oscillators (LOs).

On one hand, demonstrating a wireless link over 20 cm doesn't seem that impressive, but the data rate of more than 56 Gb/s surpasses what many cabled connections can do today. Although it's a short range, this demonstration highlights the future capabilities of wireless standards to eliminate the need for complicated wiring harnesses and multiple wired data lanes. Engineers could further expand on these capabilities by demonstrating multichannel, parallel links that rely on synchronized wideband AWGs and analyzers.

Researchers can accelerate their modeling, simulation, and system design efforts by trying out their latest ideas on easily reconfigurable, high-fidelity, and wide-bandwidth RF test beds. These flexible test beds take advantage of AWGs, oscilloscopes, and digitizers with very high sampling rates to give researchers reliable tools for design and validation of complex new waveforms, devices, and systems for 6G wireless applications.

As researchers create new prototypes, it becomes even more important to have a toolset that allows for the integration of actual measurements with system-level models. Going a step further, being equipped with analysis tools that operate both on software-modeled and simulated data, as well as actual measured data from high-bandwidth test equipment, will increase the reliability of their designs. ■

2. Shown is an example configuration of a 6G test bed with wideband signal generation and analysis. *Tektronix*



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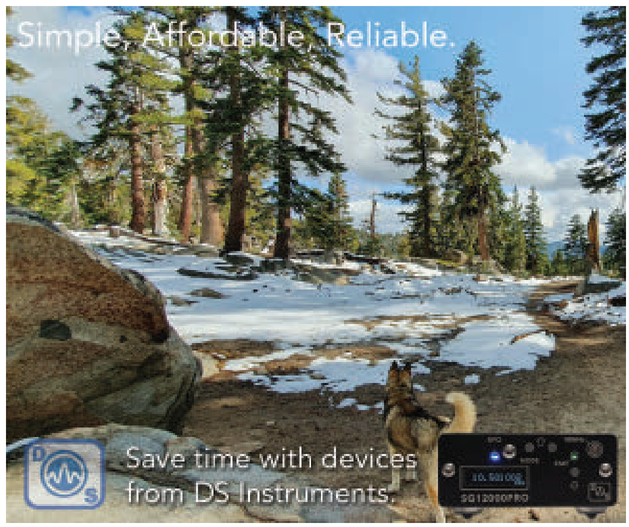

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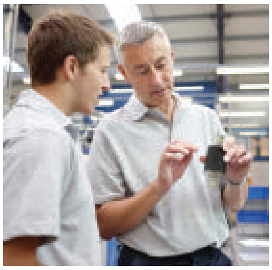

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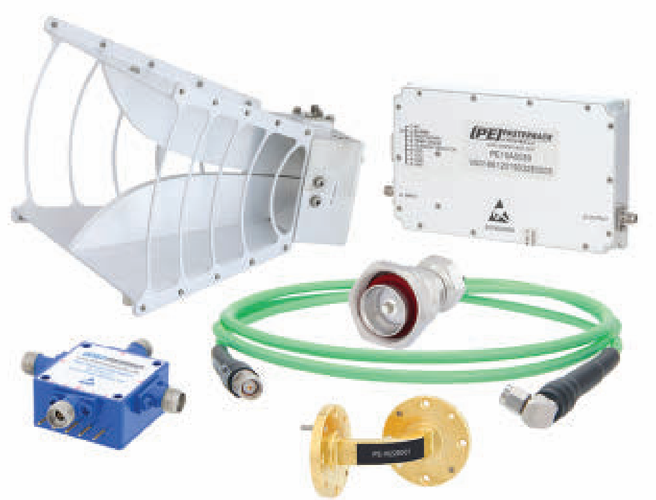

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ANDREW ROSS | Senior Product Manager, Laird Connectivity

Laird Connectivity's Andrew Ross dispels common misconceptions about the features and impact that Wi-Fi 6 and 6E will have on IoT design.

The Wi-Fi Alliance has launched two new versions of Wi-Fi that deliver significant advances in performance, efficiency, latency, and other key areas: Wi-Fi 6 and 6E. Because Wi-Fi is such a ubiquitous technology in IoT design, there's always apprehension about changes to this core connectivity technology.

By dispelling the misconceptions, what becomes clear is that these new versions of Wi-Fi provide an even stronger foundation for consumer smart devices, IoT networks, and a wide range of enterprise and industrial use cases.

1. This is a minor update to Wi-Fi. It's really only significant for niche applications.

It's not an exaggeration to compare this upgrade to Wi-Fi to the leap from 4G to 5G in the cellular world. Wi-Fi 6 and 6E will deliver major advances in performance and features that make it enormously impactful across the full range of IoT devices.

2. It looks faster. That's the biggest upgrade.

"Faster" just scratches the surface of why Wi-Fi 6 and 6E are better options. Greater device density and much-increased spectrum gives engineers more flexibility, reliability, and performance, making it the most efficient version of Wi-Fi ever delivered. Don't forget the major gains in energy efficiency, latency, and features that support both existing and new use cases.

3. The claims I've seen about speed feel like hype. It's silly to compare this to the jump in performance in cellular from 4G to 5G.

I'm always skeptical about speed claims in marketing materials, but the boost in speed is legitimate. I've read test results from respected people in the industry who have achieved increases in download speeds of 1,000%. And those results match what my own team has seen working with the technology. Part of how Wi-Fi 6 makes this happen is through its low-power claims, so that the download times and power don't waste energy.

There's a long list of data-intensive IoT use cases that benefit greatly from this increase in speed. Factory and building automation is a key one. So are automation systems in industrial settings, as well as use cases where high-quality video and audio are important requirements.

4. MIMO technology is probably the main driver for such an increase in speed. It's not big news—lots of technologies now have that.

The inclusion of MU-MIMO is a major factor, but just crediting that technology discounts how significant this upgrade is in Wi-Fi 6 and 6E. In addition to doubling the number of spatial streams using MU-MIMO, the performance of those streams is dramatically increased using beamforming techniques. Adding the ability to implement bidirectional MU-MIMO Wi-Fi 6 is the first version of Wi-Fi that allows users to access the full benefit of beamforming in noisy environments. Wider channels that include space in the 6-GHz spectrum also contribute greatly to the boost in speed.

Moreover, Wi-Fi 6/6E's extension of quadrature-amplitude-modulation (QAM) architecture is a big deal. It's the equivalent of putting a much more powerful engine into Wi-Fi, making the massive increase in speed possible.

5. I'll give you that Wi-Fi 6 is faster. But latency is still an issue.

Yes, Wi-Fi isn't yet a fit for ultra-low-latency applications like medical devices,

where latency is so vitally important. But that doesn't mean that the latency improvement in Wi-Fi 6/6E isn't significant.

Latency is approximately 3X lower than prior versions of Wi-Fi, so it may not be ready for real-time applications, but it's very close. Just as valuable is how the new version of Wi-Fi manages packets more efficiently, removing empty space so that network utilization nears 100%. Those two factors make this a major upgrade for latency-sensitive applications such as robotics, lighting controls, machine controls, and more.

6. My IoT devices don't have a lot of data to transfer, and I don't need real-time data transmission, so these latency improvements aren't relevant to me.

Wi-Fi's lower latency has a surprise benefit for battery-powered IoT devices: longer battery life. The faster speed and lower latency of Wi-Fi 6/6E reduces the amount of time (and energy) it takes for devices to send and receive data. Even when small batches of data are being sent and received, those small energy savings add up over time.

I expect further testing to reveal that these performance upgrades in Wi-Fi will add months or even years to some of the most common low-energy IoT devices.

7. Greater device density will be great for consumer environments, like when all of the kids in a family are streaming on their devices. But it's not as important for my IoT deployments.

Yes, anything that reduces family fights over connectivity is a very good thing. But every Wi-Fi network experiences congestion, which often creates performance issues that have become frustrating in high-density RF environments like healthcare facilities, airports, and schools.

By using MU-MIMO, beamforming, OFDMA, more efficient packet management, BSS Coloring, and other features allows networks to support far more devices in a given physical space while also reducing the RF noise and interference that often plagued high-density environments in the past. This also can save on the cost of infrastructure deployment, as it requires far fewer access points to support the high client counts.

8. This new version of Wi-Fi is all about speed. Hopefully, they will focus more on battery life in the next version.

No need to wait for a more battery-friendly version of Wi-Fi. This version delivers on it in a big way.

I already mentioned that this is the most efficient Wi-Fi version and discussed the impact of lower latency and packet management on battery life. But Wi-Fi 6 and 6E also have a redesigned architecture that utilizes target-wake-time (TWT) technology to manage sleep and wake cycles in a far more energy-efficient way. In addition, TWT allows you to tailor your power versus performance by application across your network by being on a per device or group level rather than the traditional singular entry access point or network level.

If you like working with prior technologies like PS-Poll (DTIM) and WMM (APSD), don't worry. Both are still available, but TWT is a major step forward because it enables much longer sleep times for clients that preserve battery through extended inactivity while remaining connected to the network.

9. The marketing about Wi-Fi 6 and 6E talks a lot about 6-GHz spectrum, but that's only relevant for advanced wireless engineers.

I don't blame you if all the GHz talk gives you a giga-headache. Discussions of radio frequencies and spectrum bands can get lost in the weeds very quickly but 6-GHz spectrum is big news for every designer of IoT devices.

Wi-Fi 6 and 6E make it simple for engineering teams to have far more wireless real estate for their networks, allowing them to optimize the performance of their devices. Got a low-latency application that you don't want to compete for bandwidth with other devices? Assign it a segment of spectrum dedicated to that use case and keep other devices in other segments of available Wi-Fi spectrum.

The process doesn't require an advanced degree in radio-frequency engineering. The new version of Wi-Fi makes it simple to put networks in portions of spectrum that best suit the application and your preferences.

10. Though these features may sound really good, antennas will no doubt lag behind and stand in the way of real-world deployments.

In this case, antennas are actually ahead of the curve. Antenna manufacturers have anticipated the use of technologies like MU-MIMO and beamforming, and they laid the groundwork for use of the 6-GHz spectrum by Wi-Fi. A wide range of options exist in the form factors that are most common for IoT devices, including flexible planar inverted-F antennas (PIFAs). The bottom line is that antenna availability thankfully will not hold back your deployment plans.

11. This version sounds plug-and-play. I won't have to alter much in my designs.

Any engineer who has worked with Wi-Fi in the past will feel comfortable working with Wi-Fi 6/6E, but there are some caveats. A few changes to hardware interfaces and logical interfaces have changed from prior versions of Wi-Fi. On the plus side, though, there's much broader OS support for Linux, Android, and RTOS, as well as full support for the latest Bluetooth versions and features.

Using Wi-Fi 6/6E will mean changes for some detailed aspects of your engineering projects. However, the dramatic improvements in speed, latency, performance, battery efficiency, and more make this well worth the adjustments needed to incorporate this new connectivity technology into your IoT strategy. ■

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Design Feature

THOMAS MILLER | Engineering Fellow, Knowles Corporation

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A SOUND PLAN: Design ANC Earphones and Hearables with Balanced Armatures

There's more than one approach to designing TWS earphones with active noise cancellation. Learn how using balanced armatures can improve quality without sacrificing audio quality.

As True Wireless Stereo (TWS) earphones become more mainstream, the consumer demands increasingly higher performance and more features, including active noise cancellation (ANC), higher-quality sound, longer battery life, and quick charging.

Balanced-armature (BA) drivers bring improved fidelity and detail over traditional dynamic drivers. BA drivers use an electronic signal to vibrate a tiny reed that's balanced between two magnets inside a tiny enclosure. The motion of the reed is transferred to a very stiff aluminum diaphragm. This diaphragm is free of unwanted resonances in the audio band, allowing it to produce maximum clarity. The high-frequency response from BAs contributes to the loud and clear audio we hear in our on-ear monitors and hearing aids, for example.

Just as sound quality is important, premium features also are making their way into TWS earphones. One of these features is ANC, which is gaining in popularity. Before COVID-19, its growth stemmed from people using it for commuting or travel. In the last year, growth was driven by people spending more time working from home and wanting a quiet, focused space.

Many headphone and hearable designers use dynamic drivers to design ANC devices. However, a BA driver also can be combined with an existing dynamic speaker in what's commonly called a hybrid earphone. In this configuration, BA drivers focus on the critical high-end portion of the audio spectrum, bringing a new level of clarity and realism.

BAs have many technical benefits beyond just sound quality. They're smaller than other drivers, incredibly lightweight, and provide greater output with less power. Due to their incredibly small size, BAs leave more room for other components or a larger battery inside hearable devices

and can allow multiple drivers to be combined to get the best sound and performance from TWS earphones.

This article presents a design guide for creating ANC earphones and hearables with balanced armatures. Modern TWS devices on the market tend to incorporate complex hardware and there's always room for improvement. Herein, we highlight how one can increase the quality of hearables without compromising the audio quality.

The first portion will discuss ANC headset designs using only BA drivers. With this design guide as reference, it's possible to create a competitive ANC system with BAs *(Fig. 1)*. The second portion will discuss designing ANC headsets using a hybrid approach with a dynamic driver woofer and a balanced-armature tweeter. With proper crossover design, the ANC performance can be enhanced by adding the tweeter.

BA-Specific Design Considerations

An ANC headset using only a BA driver can deliver noise-reduction performance comparable to one using a dynamic driver, provided certain adjustments are made. Concerns about BA phase response have proven to be unwarranted. The BA driver can even provide better passive noise reduction than a dynamic driver.

Recommended adjustments include a reduction of the vent corner frequency, adding more low-frequency boost, and a stronger 3-kHz notch to the loop filter. One also may choose to add a level compressor to make the BA output seem even louder.

About Venting

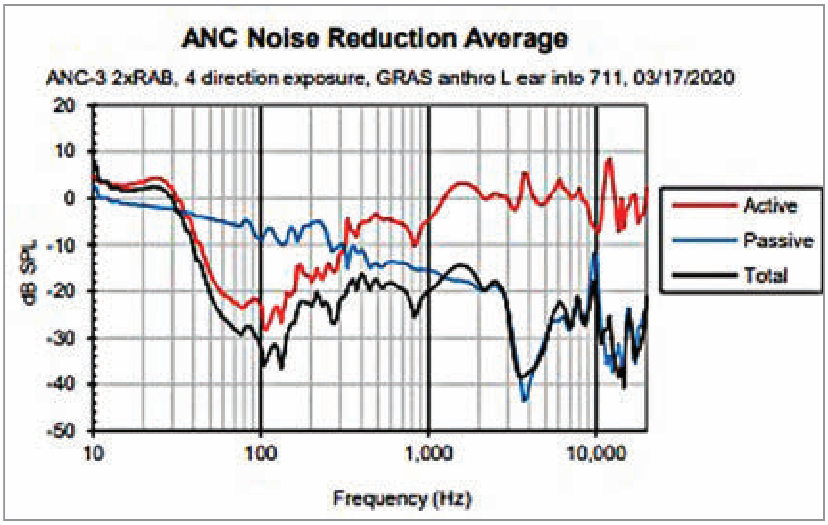
A vent path from the ear canal to the outside world reduces the level of very-low-frequency occluded sounds (jaw motion/walking) and reduces the impact of leaks on ANC performance. However, just as a vent reduces occluded sounds, it also reduces the level of bass in music playback. The attenuated bass response can be compensated for by using corresponding electronic boost, but the vent still reduces the maximum level of bass output from the driver.

Vent size can be described by the corner frequency at which sound-pressure level (SPL) in the measurement coupler is reduced by 3 dB *(Fig. 2)*. One may use vents with a higher cutoff frequency with drivers having higher maximum output capability. When a small BA driver covers low frequencies, a somewhat smaller vent enables a good balance of noise reduction and bass reproduction. We recommend a corner frequency in the range of 40 to 100 Hz.

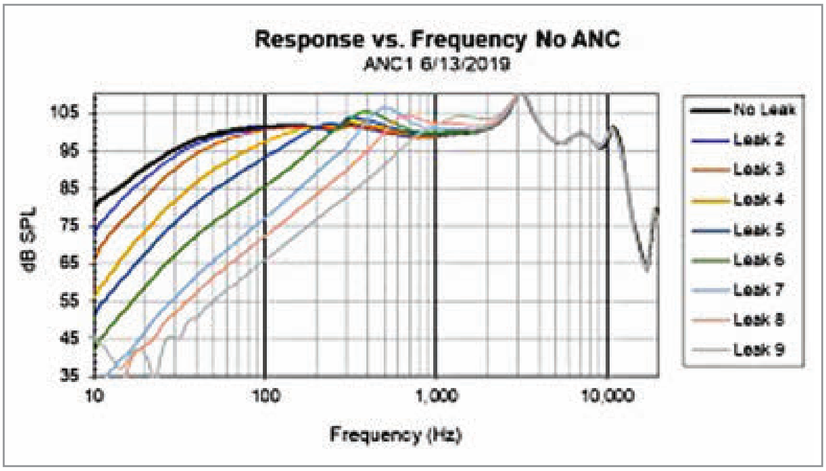
ANC Filter Design Requirements for BAs

A hybrid ANC system requires three filters: a feedback (FB) filter, a feedforward (FF) filter, and a music ANC-compensation filter. The music-filter requirements are the same for dynamic and BA drivers.

The transfer functions of the driver, both in terms of sensitivity and phase, are critical to the performance of the ANC system. Designers accustomed to working with dynamic drivers have been concerned that sensitivity and phase curves for BAs look different than for dynamic drivers.



1. This graph shows ANC performance for earphones designed with balanced armatures. *Knowles*



2. Depending on the size of the front vent, bass roll-off can vary considerably. *Knowles*

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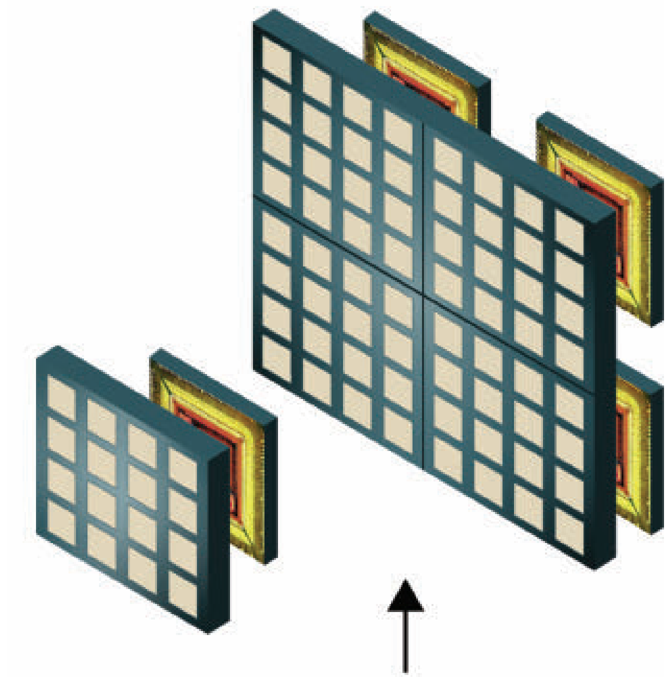

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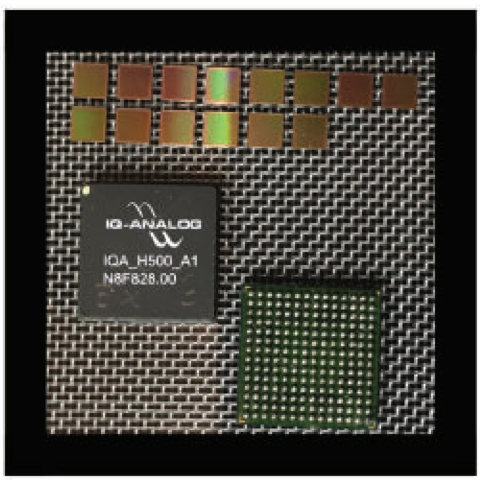

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We have carefully studied these differences and found that this should not be cause for concern. The reason is that both dynamic and BA drivers are minimum-phase-shift devices in the frequency range needed for ANC. Thus, both classes of drivers produce the minimum amount of phase shift theoretically possible given their sensitivities.

When one applies a minimum-phase type of equalizer to flatten the response curves, the phase curves also become flat throughout the ANC frequency band. Due to their minimum phase-shift properties, any gain and phase response achieved with a dynamic driver can always be matched when using a BA driver after applying a suitable adjustment of the associated feedforward or feedback filter. Once the gain of the BA driver is adjusted to meet the open-loop filter target response, the open-loop phase will look nearly the same as it would have for a dynamic driver.

Passive Attenuation

The backside of the headphone driver is typically vented to the outside world. As a result, the driver's diaphragm can move more freely, increasing the bass output to the ear. However, this also provides a path for outside sound to enter the ear. A BA driver provides more passive attenuation of the sound due to its higher mechanical stiffness. This slightly reduces the amount of active noise cancelling needed above the vent cutoff frequency.

Applying a Peak-Level Compressor

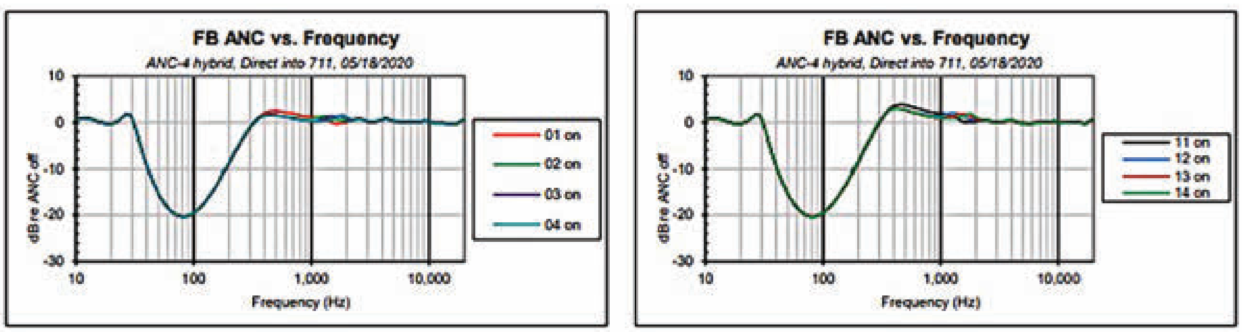
While BA drivers offer very high efficiency for their size, small-sized BA drivers will have a lower maximum output rating than a 6-mm or larger dynamic driver. This doesn't keep them from being effective in ANC in most situations, but it could result in sounds of distress when short-term peaks occur.

One very effective solution for this issue is to use a peak compressor. It will limit the signal level sent to the speaker when there are loud sounds. The technique is widely used with portable Bluetooth speakers to give the illusion that they're bigger than they really are. The audibility of the limiting can be minimized by using a fast attack time (5:1).

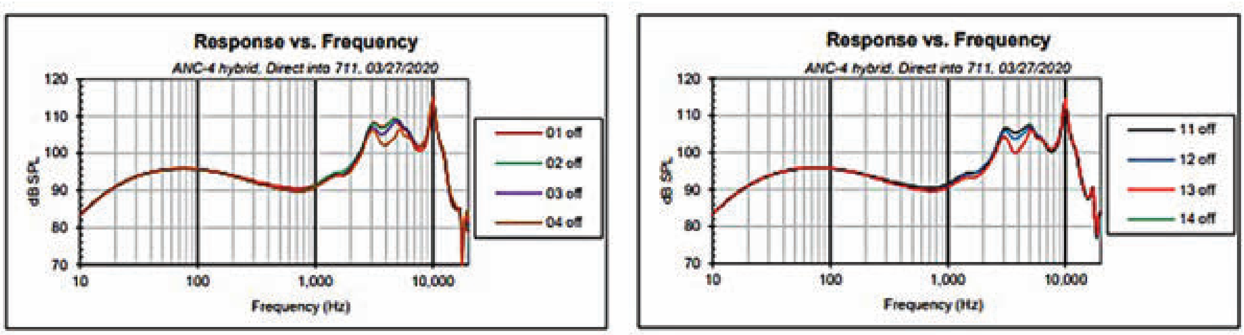
The peak limiter can be placed in different points in the signal chain. The placement may be limited by the flexibility of the device that's performing the ANC computation. The simplest method is to place the limiter after all signals have been combined, just ahead of the digital-to-analog conversion. This assures that the combined music, FB, and FF paths don't exceed a preset limit.

No matter how the earphone is used and what sounds occur in the environment, the BA speaker will be protected and will not produce any sounds of distress. If there's an excessively loud sound, the amount of noise reduction will be momentarily reduced. Full ANC will be restored as soon as the peak passes.

A potential limitation of this arrangement is that any one of the signals will change the performance of the others. For example, bumping the earphone will cause a large FB signal, resulting in the music level being momentarily reduced.



3. These graphs depict hybrid earphone noise reduction with various woofer and tweeter filter orders (xy = woofer-tweeter order). *Knowles*



4. Here, we see plots of hybrid response with ANC off and various woofer and tweeter filter orders (xy = woofer-tweeter order). *Knowles*

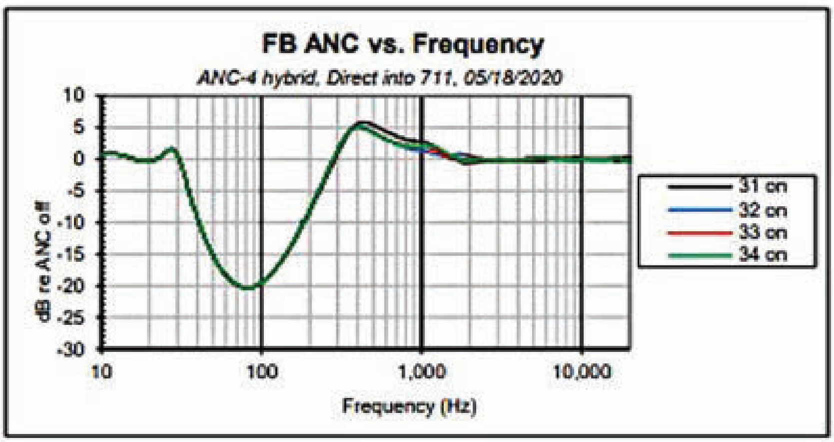
While peaks can occur in any of the FB, FF, and music paths, the FB path is the one most likely to have large peaks. Therefore, it may be useful to place the peak limiter solely in the FB path. This will assure that the FF and music performance will not be adversely affected by any infrasound occurring within the ear canal. The choice of limiter location depends on the expected signal levels for the various signal paths.

Multi-Driver ANC

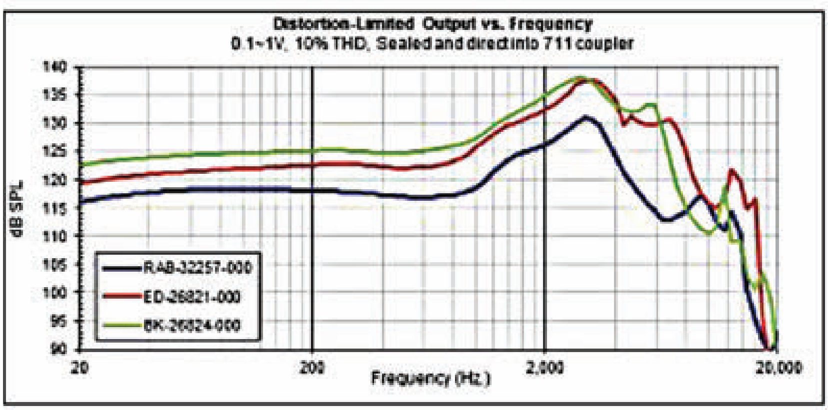
Hybrids employ a dynamic-driver woofer and BA tweeter to leverage the advantages of both. Dynamics typically have ample low-frequency output. BA tweeters provide high-frequency extension, high dynamic range, and excellent detail.

When a BA covers the treble range, the dynamic driver may potentially be smaller and tuned for optimal low-frequency performance. It also provides the designer more freedom in placing or angling the woofer relative to the ear-tip exit of the housing. Moreover, one can design a multi-way system using a large BA driver as the woofer, and a smaller BA as the tweeter.

When designed properly, adding a second driver doesn't interfere with the ANC system. The key factor is to minimize phase lag in the woofer channel. This is done by using a low-order filter design for the woofer. Phase lag in the tweeter channel is much less important because it typically occurs above the frequency range in which the ANC system is active.



5. Shown is the unwanted ANC gain as result of using a high-order woofer filter. *Knowles*



6. This plot illustrates maximum output vs. frequency for 10% THD for three BA families. *Knowles*

In any multi-way earphone, a crossover network divides energy to appropriate drivers. Excellent performance can be obtained even without a low-pass filter on the woofer (or a simple acoustic filter) and a single capacitor acting as high-pass filter on the tweeter. An active crossover also is possible in TWS earphones by using both outputs from the digital signal processor (DSP) to drive the woofer and tweeter separately. In either case, it's possible to design the crossover to be compatible with ANC.

We studied a wide variety of crossover designs using simulations and confirmed them with measurements. These experiments yielded some valuable observations:

- Zero or first-order low-pass woofer filtering works best for stability.
- A crossover frequency of 4 kHz or higher works well for stability and audio performance.
- Tweeter filter order isn't critical.

Figure 3 shows the amount of noise reduction. *Figure 4* compares the music playback response with ANC turned off.

Higher-order woofer filters cause excessive phase shift, which degrades stability. *Figure 5* shows the same earphone using a third-order filter. The ANC system experiences net gain instead of attenuation from 300 Hz to 1.5 kHz.

Recommended BA Models for ANC

If using a BA for low frequencies, it's helpful to select a back-vented design. This provides low-frequency extension almost to dc and reduces low-frequency distortion. In addition, larger BA models will provide greater output, enabling proper cancellation of louder noises, and/or lower-resistance headset venting.

Because they have reduced output near 200 Hz, which is useful for avoiding muddy bass, resistive back vents are popular for wired headphones. However, for ANC applications, it's helpful to use a non-resistive vent to maximize the output near 200 Hz. Then, electrical equalization is applied to reduce music bass output near 200 Hz, improving timbre and system headroom.

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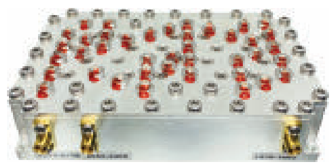

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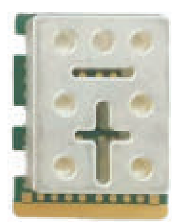

JQL manufacturers a range of filters from 30 MHz up to 40 GHz in various topologies. The current output is approximately 5000 filters a month which includes global commercial and military market. Ceramic and ceramic waveguide filters consume nearly 70% of the capacity.

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When selecting a tweeter, one with a larger sound port can reduce the inertance of the device, boosting output at very high frequencies. If the system doesn't have room for an electrical crossover, there's a model with an acoustical crossover available.

Acoustic engineers working on TWS solutions should take advantage of the small size, low power, and premium sound that balanced armatures offer for ANC earphones. *Figure* 6 shows maximum output vs. frequency for 10% total harmonic distortion (THD) for three of Knowles' BA families, while the *table* provides recommendations for various ANC applications.

Summary

Those experienced in designing ANC earphones with dynamic speakers will find that with the help of this guide, only small changes are needed to adopt a pure BA or hybrid configuration. Remember that the BA should be selected to meet the maximum output requirements. The front vent should be chosen for an appropriate tradeoff between occlusion reduction, user variations, and low-frequency output requirements. The feedback-loop filter should be adjusted to reduce phase shift at the low- and high-frequency extremes of the ANC range.

At low frequencies, a second-order shelving filter boost may help to reduce the phase shift. At high frequencies, a notch filter matching the mechanical resonance of the driver is needed. If designing a system with a woofer and a tweeter, use a low-order filter—or none at all—for the woofer to avoid excess phase shift. ■

BA Type	Model	DCR	Comment
Full range	RAB-32033-000	22 Ω	Large back vent
Tweeter	WBFK-30095-000	12.5 Ω	With typical port tube
Tweeter	WBFK-33873-000	13 Ω	With large sound port for greater HF output
Tweeter	WBFK-33326-000	12.5 Ω	With acoustic high pass for crossoverless designs

Recommended BA models for ANC applications. The smallest full-range model, RAB, is listed here. Larger models with higher output also are available. *Knowles*

GREG ARMSTRONG | Principal Engineer – System Design, Renesas Electronics

5G Synchronization for Cost-Sensitive Cable Modems

Get an insider's look into a new approach for designing 5G radio access networks (RANs).

5G radio access networks (RANs) require a new approach to designing and building networks. Work by organizations like CableLabs is spawning specifications for mobile backhaul over the cable network that can address the performance requirements of 4G/LTE and 5G RAN.

The existing Data Over Cable Service Interface Specification (DOCSIS) hybrid fiber coax (HFC) infrastructure provides many advantages for wireless backhaul. For example, a North American operator case study found that all of the ideal small-cell locations were within 10 meters of coax.

DOCSIS transport itself is synchronous in nature and uses a common clock derived by the cable-modem termination system (CMTS). This clock has a ±5-ppm clock accuracy.

DOCSIS 3.1 introduced the DOCSIS Timing Protocol (DTP) to measure the asymmetries in the HFC network and provide an adjustment factor to the DOCSIS timestamp. It allowed for much more precise time distribution over the HFC, including synchronizing the DOCSIS domain to a network source, such as a Primary Reference Time Clock (PRTC).

Mobile Backhaul

A CableLabs committee made up of industry experts recently looked at mobile backhaul over DOCSIS. The committee saw the need for 4G/5G synchronization within the cable modem (CM). *Figure 1* shows the new DOCSIS 3.1 domain providing mobile-backhaul synchronization. Mobile backhaul refers to the network providing connectivity between the mobile switching core (or what's also known as the evolved packet core [EPC] for LTE, or next-generation core [NGC] for 5G) and the RAN node.

DOCSIS 3.1 introduced a new modular headend architecture (MHAv2) that required a remote DOCSIS timing interface (R-DTI) through the converged interconnect network (CIN). CableLabs also is working to define R-DTI.

If the DOCSIS network is providing the backhaul service, it now needs to be part of the timing distribution chain, carrying precision timing down to the CM and into the Wireless End Application (WEA) network. The DOCSIS Timing

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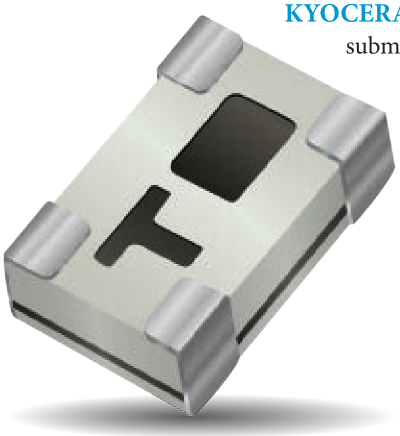

KYOCERA AVX has an abundance of patents, continues to invest heavily in R&D, and submits several new patent applications every year to further expand the company's strong technology base with newly innovated, next-generation product solutions.

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Protocol (DTP) was designed to carry this precise timing, enabling the DOCSIS link to work with other elements of the operator's network to meet the overall timing requirement needed by the radio base-station slave clock. *Figure 2* shows an example deployment scenario of the current mobile backhaul.

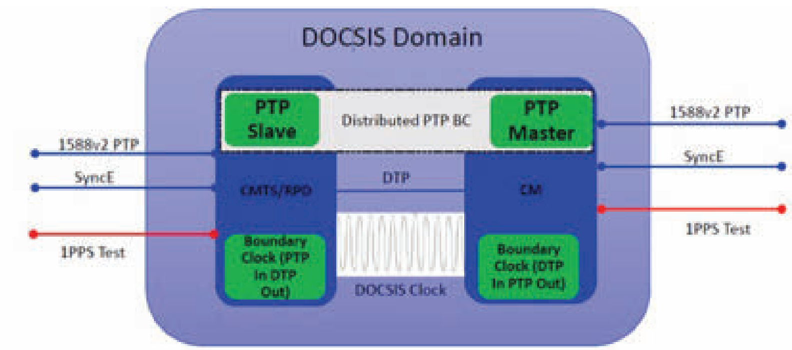
The primary focus of the present release of the DOCSIS synchronization techniques specification (CM-SP-SYNC) is on the mobile-backhaul (MBH) application. A MBH network connects the mobile switching core (EPC or NGC) and the RAN node. The CM-SP-SYNC document looks at using DOCSIS technology to carry precision frequency and/or phase synchronization signals; with the hybrid fiber-coax (HFC) plant as a segment of an operator's overall timing-distribution chain.

Traditional mobile base stations need to be frequency-synchronized to establish proper frequency alignment, which guarantees certain network key performance indicators (KPIs) such as successful call establishment and handover. In addition to frequency synchronization, LTE TDD and the latest generations of mobile technologies such as LTE-A, which include coordinated multipoint (CoMP) and enhanced inter-cell interference coordination (eICIC), all require stringent time and phase synchronization.

Supporting such features places additional synchronization requirements on the mobile backhaul network. Because this article focuses more on the CM as a synchronous network equipment master clock, we will not go into the details of these synchronization requirements. Instead, please refer to CM-SP-SYNC Appendix III for a technical overview.

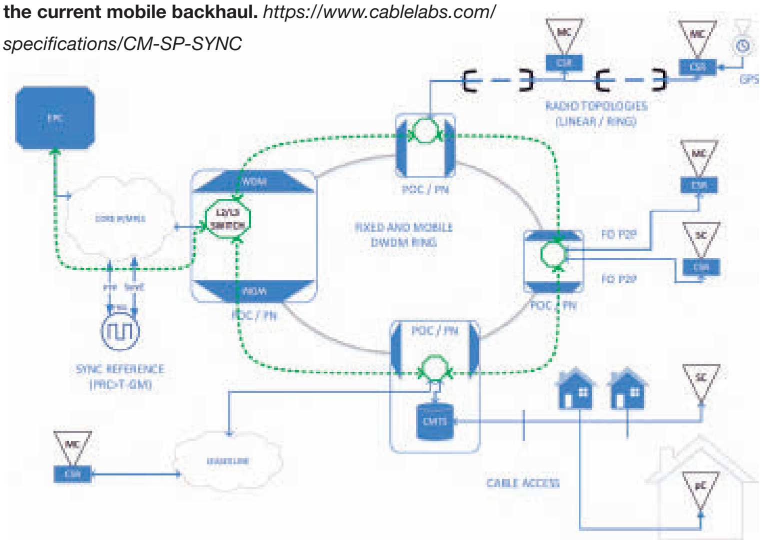
Reference System and CM-SP-SYNC

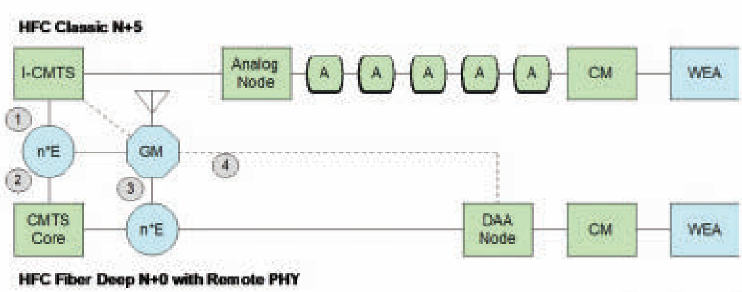
To provide MBH service over the DOCSIS network and the HFC plant, we must first look at a reference system. *Figure 3* is taken from CM-SP-SYNC and shows the reference system's connectivity to GNSS. For 4G/LTE and 5G mobile services, the maximum time error (max|TE|), which includes all time-error sources, has a target of 1,500 ns. The time-error budgets comprise multiple components:



1. Shown here is the new DOCSIS 3.1 domain providing mobile-backhaul synchronization. *Renesas Electronics*

2. This image depicts an example deployment scenario of the current mobile backhaul. *https://www.cablelabs.com/specifications/CM-SP-SYNC*





3. Shown is DOCSIS's and HFC Plant's system connectivity to GNSS. *https://www.cablelabs.com/specifications/CM-SP-SYNC*

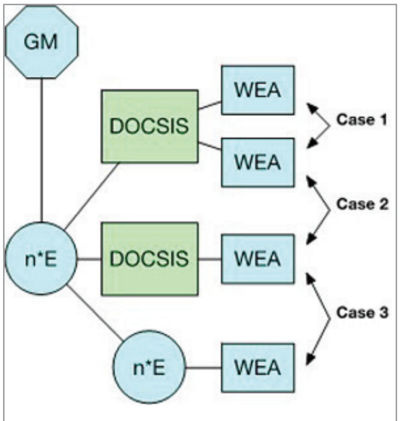
- **Constant time error (cTE):** Error that doesn't change in steady state.
- **Dynamic time error (dTE):** Error that does change in steady state (per ITU-T G.8273.2, fast changes are >0.1 Hz and slow changes are <0.1 Hz).
- **Rearrangement:** Abrupt changes caused by network reconfiguration.
- **Holdover:** Long-term stability in case of reference source failure.

The CM-SP-SYNC specification allows for the cable operator to mix and match different classes of equipment, different numbers of Ethernet switch hops, and different DOCSIS network architectures to arrive at its own network design—if the overall target is maintained at the mobile base stations. To help, CM-SP-SYNC splits the DOCSIS reference system into three distinct network segments and allocates a time-error budget to each network segment. The remainder of this article focuses on the WEA network, from the CM to CPE interface (CMCI) port to the WEA air interface.

Wireless End Applications

There are three cases of how WEAs are related through the DOCSIS network *(Fig. 4)*. The "E" in *Figure 4* represents an Ethernet switch, which can be a participant node (a boundary clock, or BC) or a non-participant node.

- **Case 1:** Two WEAs, typically two small cells, connected to the same DOCSIS network. Time error is contained within a single DOCSIS network.
- **Case 2:** Two WEAs, typically two small cells, connected to different DOCSIS networks. Time error is distributed across two DOCSIS networks and an IP network segment.
- **Case 3:** A WEA connected to a DOCSIS network that's communicating with a macrocell WEA on a separate IP network segment. Time error is distributed across a DOCSIS network and an IP network segment.



4. These are three cases of how WEAs are related through the DOCSIS network. *https://www.cablelabs.com/specifications/CM-SP-SYNC*

For mobile backhaul, the CM provides phase and frequency synchronization services upstream to the WEAs. From the WEA's perspective, the CM is a synchronous network equipment master clock. However, the CM is a "dumb" node in the DOCSIS network and always works in conjunction with the CMTS, including deriving its DOCSIS timestamp from DTP.

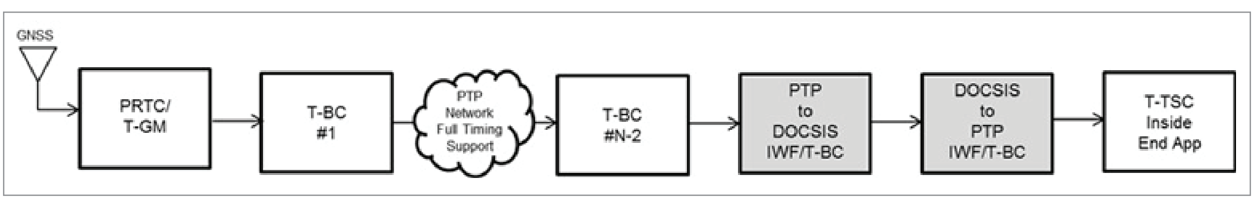
For this reason, we must look at the DOCSIS equipment as an Inter-Working Function (IWF) used to convert PTP and SyncE to the DOCSIS protocol (running on the I-CMTS, RPD, or RMD), and as a second IWF used to convert the DOCSIS protocol (running on the CM) back to PTP and SyncE. *Figure 5* shows a generic example deployment scenario with DOCSIS equipment.

The ITU-T coined the term IWF to describe synchronization network segments that are running different PTP profiles (see ITU-T G.8285 Appendix III). However, it also can be used to describe the DOCSIS network segments running both PTP and DTP. IWF is used throughout CM-SP-SYNC to describe the DOCSIS network segments, including for the CM that's performing the DOCSIS-to-PTP IWF/T-BC.

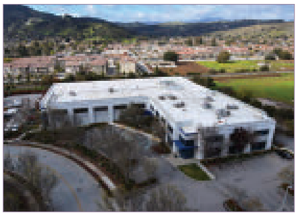
The intention of the IWF is to faithfully replicate the functionality of [G.8275.1] from a PTP profile point of view. That includes the operation of the Best Master Clock Algorithm (BMCA), the transfer of all PTP fields (such as those in the Announce messages), and other information. This IWF model approach is used for the DOCSIS network. *Figure 6* shows an example component-level block diagram for the CM performing the DOCSIS-to-PTP IWF/T-BC.

As a synchronous network equipment master clock, the CM must provide two clocks:

- A frequency clock over the physical layer, per ITU-T G.8262 Synchronous Ethernet Equipment Clock (EEC, or SyncE).
- A phase/time clock over the packet layer, per ITU-T G.8273.2 Telecom Boundary Clock (T-BC). This includes running two protocols: 1) ESMC (ITU-T G.8264); and 2) PTP (following the port state protocol as defined in IEEE 1588-2008). The protocols are out of the scope of this article.



5. Here's a depiction of a generic deployment scenario with DOCSIS equipment. *https://www.cablelabs.com/specifications/CM-SP-SYNC*



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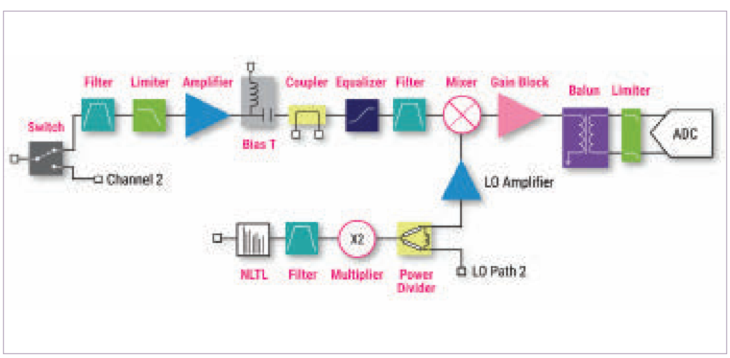

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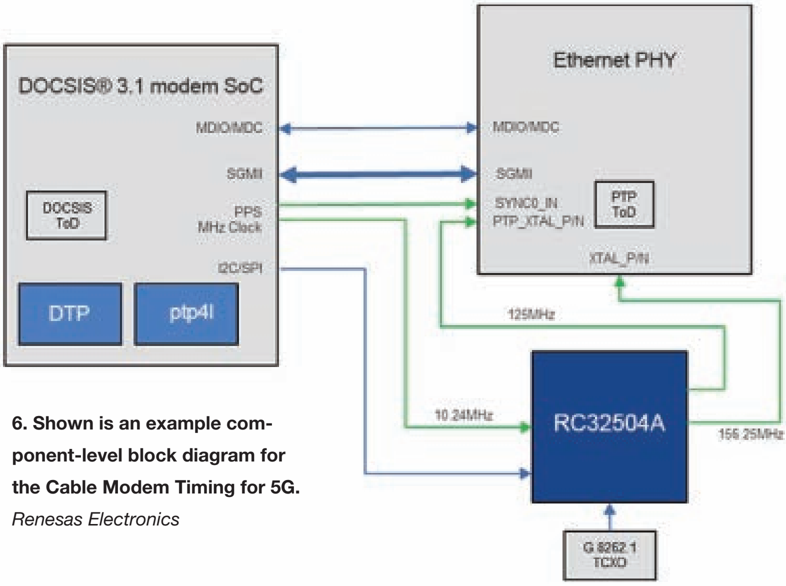

6. Shown is an example component-level block diagram for the Cable Modem Timing for 5G. *Renesas Electronics*

Counting on the Clocks

Looking at the network clocks, the CM alone doesn't provide the clock performance. You must look at the DOCSIS system as a two-box system. In other words, the total DOCSIS synchronization portion of the chain should meet the performance requirements when measured in isolation, between the PTP input on the first IWF (PTP-to-DOCSIS) and the PTP output on the second IWF (DOCSIS-to-PTP).

The performance requirement is covered in ITU-T G.8273.2, Appendix V, "Performance Estimation for Cascaded Media Converters acting as T-BCs." However, the CM time error isn't specified to fully follow [G.8273.2]. The CM must comply with only the following max|TE| and cTE requirements shown in the *table*, excluding DTP.

The resulting DOCSIS timestamp will generate a counter that increments at a rate of 10.24 MHz for a period of approximately 97.66 ns. This will need to be converted to a PTP timestamp, which is a counter that increments at a rate of 1 GHz for a period of 1 ns. Some CM may provide a finer time resolution for the DOCSIS timestamp using an increment at a rate of 20 × 10.24 MHz, or 204.8 MHz, for a period of approximately 4.88 ns.

Either way, a synthesized clock representing the DOCSIS timestamp (i.e., 10.24 MHz or 204.8 MHz) can be locked to by a silicon phase-locked loop (PLL) to rate-convert to an Ethernet physical-layer reference clock and PTP timestamp counter clock. Because both timestamps are based on International Atomic Time (TAI) starting 00:00:00 January 1, 1970, no starting offset is required, and a simple 1 pulse-per-second (1-PPS) trigger can be used to synchronize the time of day (ToD) between the two timestamp counters. This is because the PLL takes care of the rate conversion (with 0 PPM translation error, so no need to worry about remainder of a division operation).

Because DTP is unidirectional for timing, it only makes sense for the CM to act as a synchronous network equipment master clock. This means the CM will look like the SyncE master for physical-layer timing and as the PTP GrandMaster (GM) for packet-base timing.

To improve the filtering of the clock for use as a master clock, it's recommended to use a temperature-compensated crystal oscillator (TCXO) for the CM's local clock source (both for the physical layer and the PTP timestamp counter). This would allow for filtering of the DOCSIS symbol clock using bandwidths below 10 Hz. It also will enable the CM to provide frequency holdover capability upstream on the loss of DTP.

However, most WEA equipment will have its own holdover capability or maintain alternate sources for time, allowing for a more cost-sensitive solution without a TCXO. In this case, a simple crystal (XTAL) can be used or even silicon clock attenuator with an integrated XTAL.

Off-the-shelf simple frequency-converting clock synchronizers that meet traditional telecom filtering requirements as defined by the ITU-T are becoming more readily available. As the RAN moves toward a more open architecture, it also means the transport of the backhaul or even fronthaul networks could go over non-traditional telecom networks, such as cable. This requires these networks to now service timing-related capabilities without disrupting their existing core services.

CableLabs has already defined mobile-backhaul requirements over the cable network. Now, cable-modem equipment manufacturers can address timing by using these new clock synchronizers and meet the performance requirements of 4G/LTE and 5G RANs. ■

DOCSIS-to-PTP IWF Performance

Class	cTE (ns)		max|TE| (ns)	
	T-BC [G.8273.2]	T-BC-DOCSIS IWF	T-BC [G.8273.2]	T-BC-DOCSIS IWF
Class A	±50	±250	100	300
Class B	±20	±100	70	150

(Source: https://www.cablelabs.com/specifications/CM-SP-SYNC)

KEN GHADIA | Senior Sales Engineer, TechnoTronix

TechnoTronix

What Makes **RF PCB Design** and Manufacturing So Complex?

This article discloses why the design and manufacturing of an RF PCB has become so involved, and why it's not every contract manufacturer's cup of tea.

When it comes to the design of RF printed circuit boards (PCBs), the degree of difficulty increases as signal frequencies move through the 100-MHz mark. The design process can have a huge impact on the quality and yield of RF PCB production. It's critical to follow all recommended design and layout guidelines while building a high-speed, mixed-signal circuit board.

Issues like a radiating antenna interfering with the analog circuit or the impact of external noise on power-supply lines are common in RF PCBs. And accurate isolation of analog and digital ground is quite challenging during the layout design of a multi-layer PCB. All of these intricacies make it hard to design and manufacture RF PCBs.

The applications of radio-frequency PCBs are diverse, encompassing wireless technologies, smartphones, sensors, automotive, aerospace, military, robotics, and more.

Some of the significant merits of RF PCBs include faster transmission of high-frequency signals due to lower impedances, easy placement of fine-pitch components, and optimized performance with multi-layer board stackup. Plus they're able to operate in a high-temperature environment.

However, the noise sensitivity, strict impedance margins, and complex layout design make it difficult for designers to build working RF PCBs in one iteration.

Key PCB Design Considerations

- In RF circuits, traces should have controlled impedances, enabling the transfer of maximum signal power from a source to the load. Multiple factors affect the characteristic impedance of these traces, including the dielectric of the PCB substrate, trace width, thickness,

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Privately held, Micro Lambda Wireless Inc. has been formed from a core of individuals with specialized YIG-based component experience combined with analog, digital, and PLL specialists to yield a strong, dynamic technical staff. High-volume manufacturing techniques have been implemented across all product lines along with standardized mechanical and electrical design, which lend themselves to low-cost and high-volume applications.

We maintain a commitment to Total Quality Management and Just-in-Time concepts throughout the organization. Our integrated manufacturing system combines sales orders, word orders, accounting, inventory, and scheduling. Material planning is supported by an MRP module, which coordinates subcontractor material requirements. Product standardization focusing on a repeatable manufacturing process enables our company to stock material, allowing for very short build cycles.

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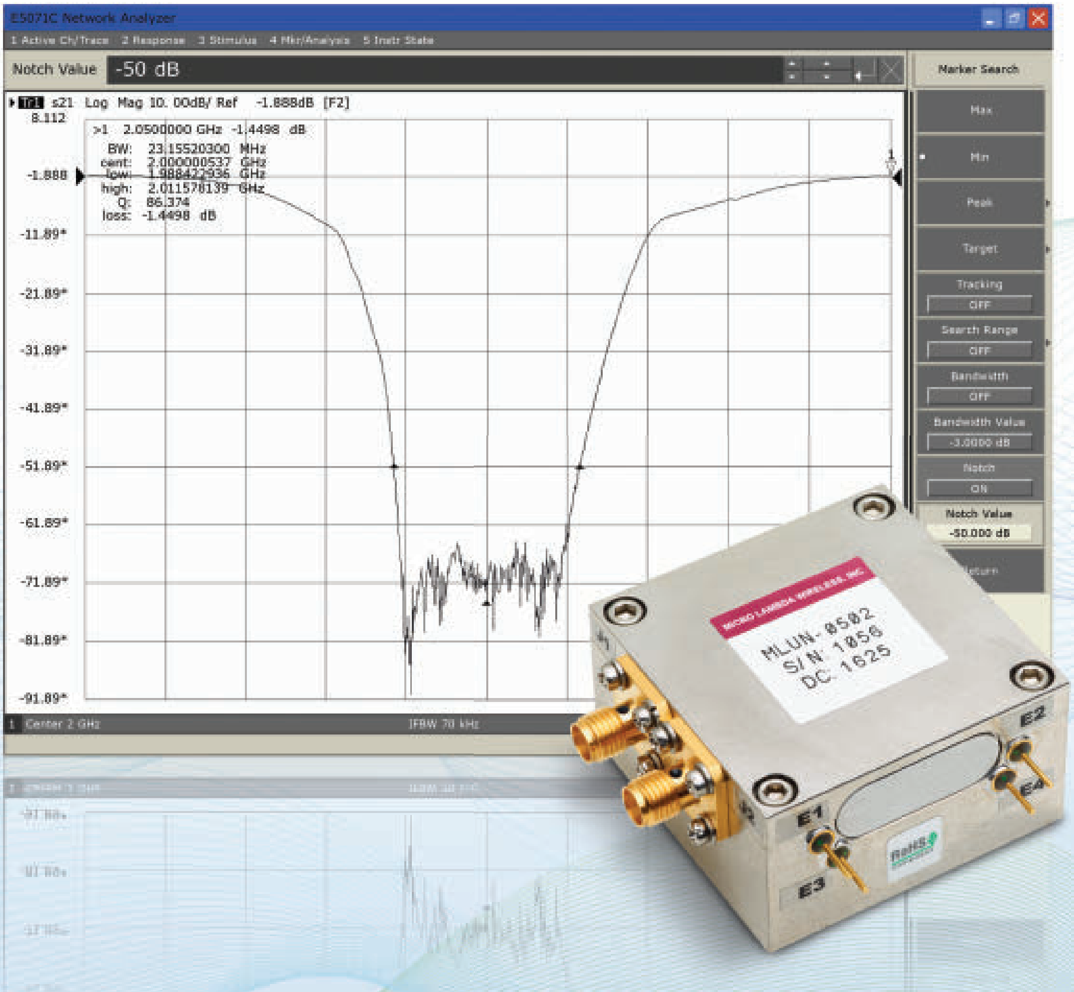

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geometry, and distance from the ground plane.

- The RF PCB material must meet the requirements of the high-frequency operation. It should offer low signal losses, the ability to absorb excess board heat, and steady performance over a broad frequency range.
- Reducing noise impact is crucial in RF PCBs, as they're very sensitive during high-frequency operations. Designers must fully isolate the analog and digital grounds in the RF PCB layout. Suitable power-decoupling capacitors are mandatory to filter the noise in the power lines.
- The analog circuits on the RF PCB can incorrectly pick up the antenna signal and manipulate the input of analog-to-digital converters (ADCs). While placing RF transmit and receive circuit components, it is necessary to consider such interference issues.

Recommendations for RF PCB Design

With the above design considerations in mind, what follows are some guidelines to assist you in building a better-performing RF PCB. It starts from the right material selection to using EDA tools for routing and signal-integrity simulations:

- Substrate material should be made of polytetrafluorethylene (PTFE) or ceramics. Material parameters like dielectric constant, loss tangent, and coefficient of thermal expansion (CTE) should stay consistent during high-speed PCB operations. Rogers substrates are ideal for RF applications.
- Strategic component placement is advised in RF PCB design. The effective method is to first place all of the RF circuit components with the desired orientations targeting short trace lengths. Input and output RF circuit components should be placed far apart to avoid any spurious signal interference. In addition, high-power and low-power circuits should be separated.
- RF traces are susceptible to transmission losses and interference issues. It's suggested to keep these trace lengths short to reduce signal attenuation. Curved bends of traces are better than sharp 90-degree turns for RF signals.
- The RF components and traces should have exclusive return ground paths. The board stackup must include a dedicated and uniform GND plane for each RF signal layer.
- Test points or vias should not be placed on the RF traces. Vias can induce capacitance in circuit boards, affecting high-frequency operations. If they must be included in any case, then reduce the RF trace routing through these vias between the layers.
- In RF PCBs, use decoupling capacitors to filter the noise in the power lines. Choose capacitors with a self-resonant frequency close to the noise frequency to maintain minimum impedance. Place the decoupling capacitors near the power device in the same layer.
- To reduce manual errors in component placement and routing, it's recommended to use automated design tools. They ensure correct RF trace shapes, chamfering to reduce discontinuity in impedance, precise via stitching, and many other intricate tasks. It becomes simpler to design the RF circuits by setting the design rules in the EDA tool.

A well-designed RF PCB may still fail as a final product if the PCB manufacturing process isn't on par with the standards of high-speed PCB production.

Common Issues in RF PCB Manufacturing

The laminates used in RF PCBs are costly and have unique mechanical characteristics. Fabricating RF PCBs with such laminates requires superior processing techniques. Choosing an experienced PCB manufacturer is crucial while building RF PCB products to avoid material waste, anticipate manufacturing issues, and suggest possible solutions.

High-frequency laminates are softer compared to the regular PCB substrate material. Hence, the scaling factor must be compensated for in advance by the PCB manufacturer. This is important to ensure that the PCB layers retain the set dimensions after the lamination process. Substantial deformations in the PCB laminate can affect the performance of the final product.

Bonding different layers of a multi-layer PCB demands an effective surface preparation process. Materials like PTFE that are used in RF PCBs tend to be relatively fragile and can easily get distorted if not handled carefully.

The CTEs of different materials used in the multi-layer stackup should match for uniform expansion under thermal stress. The possibility of material waste increases if the PCB manufacturer isn't adequately skilled in fabricating high-frequency PCBs.

The materials used in RF PCBs are expensive. If damaged during the fabrication process, replacing them will delay the overall manufacturing schedule. Thus, the production yield depends on using the correct process settings and appropriate machinery.

Conclusion

Building a successful RF PCB is complex yet possible by skilled designers and fabricators. Adhering to the design and manufacturing checklists is one of the key factors when developing RF PCBs. Using the latest EDA tools can simplify the placement and routing of complex circuitry in the design stage. In addition, choosing an experienced PCB manufacturer that's equipped with suitable tools and processes can ensure a high-yield RF PCB production. ■

JAMES MORRA | Senior Editor

Engineers are in High Demand—

Most are Not Missing the Opportunity

Our latest Salary Survey revealed that 70% of engineers expect to see their compensation go up this year, as employers continue to compete over hard-to-find expertise.

As electrical and electronics engineers find themselves in high demand, they're pushing their employers to raise salaries, increase bonuses, and offer other perks to complement their pay increases this year.

Around 70% of respondents say that they will see their compensation grow in 2022, up from about 60% in the same situation just last year, according to data from the latest annual survey from *Electronic Design, Microwaves & RF*, and Endeavor Business Media's Design Engineering Group. The results signal that engineers still have a strong hand to play when it comes to getting raises and bonuses, as companies compete over scarce talent to fill open positions.

Only a fraction of the nearly 600 respondents, ranging from rank-and-file design engineers to those in executive and engineering management roles, anticipate a reduction in their overall pay this year.

"There will always be new technologies to integrate and old systems becoming obsolete," said one of the respondents to the survey, which polled engineers about their salaries and other forms of compensation. "The opportunities to contribute will never go away."

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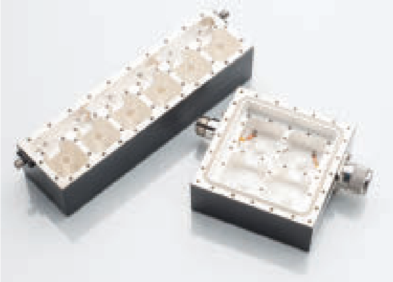


Typical applications for NIC's products include communications, navigation, guidance, surveillance, point-to point and multi-point radio systems, radar systems, and satellite systems.

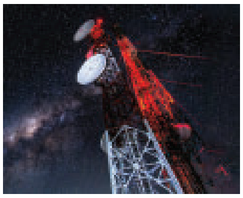
NIC's product portfolio includes Lumped Component Filters, Cavity Filters, Ceramic Filters, Crystal Filters, Diplexers, Multiplexers, Integrated Microwave Assemblies, Switched filter banks, Phase shifters, Filter/amplifiers, and Filter/limiters.

CAPABILITIES & TECHNOLOGY

NIC is a vertically integrated company that maintains all assembly and testing in its 15,000 sq. ft. facility with the flexibility to handle high volume and high product mix. NIC operates a state-of-the art in-house suite of environmental testing that is compliant with MIL-STD-202, MIL-STD-883, as well as space-level screening.

NIC is certified as a Small Business, ISO 9001 accredited, AS9100 certified and has DoD Facility Clearance.

NIC has consistently incorporated industry-leading design techniques and technologies to create practical, cost-effective, and repeatable solutions. NIC's staff engineers have >100 years in RF design experience and are staffed to provide quick-turn prototypes.



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- Low Profile (< 0.10")
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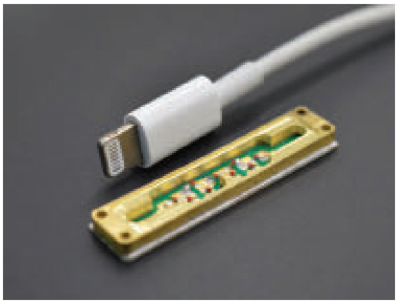
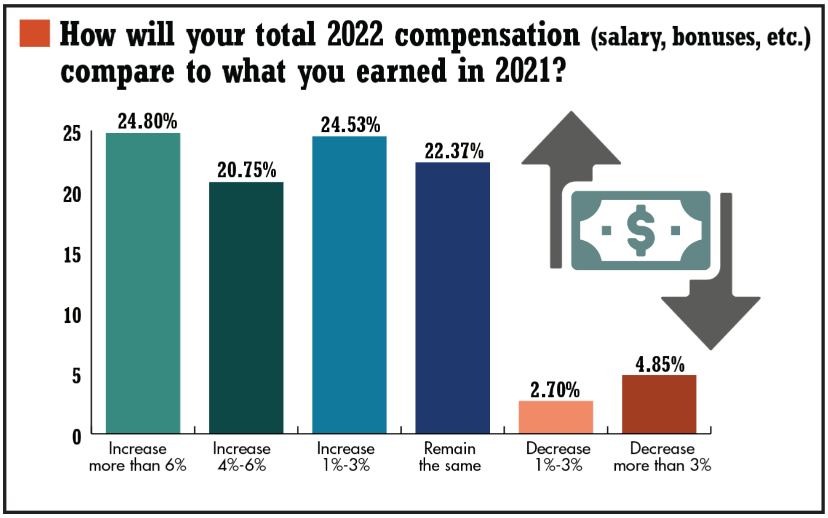


NIC

As most electrical and electronics engineers will tell you, not everyone can do what they do. But while they tend to regard engineering as more of an identity than a profession, they always have money on the mind. Each year, compensation ranks as one of the top factors in their job satisfaction, rivaling the rush that comes with the challenges of designing a new product and the impact their innovations have on the world at large.

While engineers continue to struggle with long hours, tight deadlines, and continuous education, they're prospering for the most part, as rising consumer prices and strong demand for workers help drive up wages.



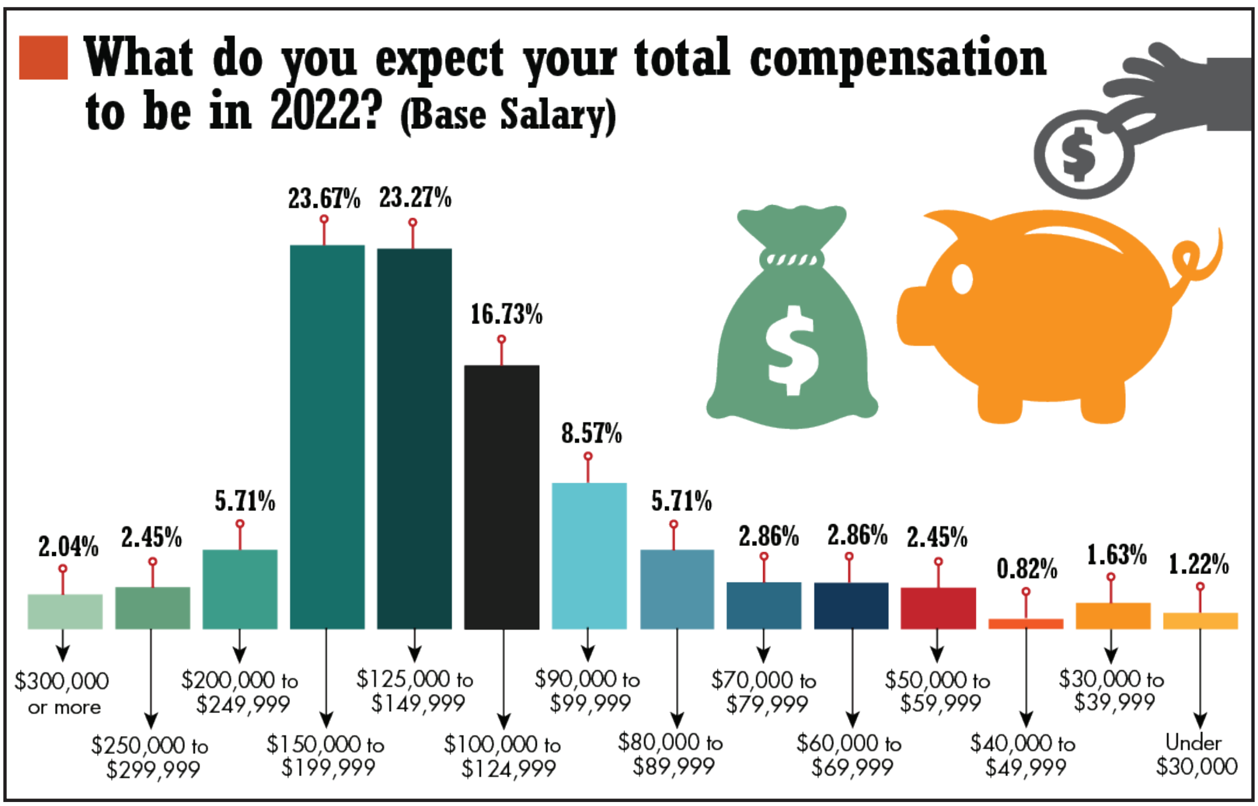
Bonus Points

While the economic fallout from the pandemic weighed on wages in 2020, times are changing. Last year, many employers doled out bigger pay increases to attract and retain skilled engineers in a tight labor market.

Some warned that high inflation threatens to wipe out many of their pandemic-era pay increases. However, the survey reveals that most professional engineers will still see strong gains in overall compensation this year.

Employers are putting more money into the pockets of electrical and electronics

> "Technology is constantly evolving. Those that can train themselves in a skill that is or will be in high demand will do well."



engineers apparently across the board. Among the engineers who responded to the survey say that they expect to have a median base salary of $125,000 to $149,999 in 2022 *(see figure, p. 48)*. More than 60% of respondents said their base salary will fall into the range of $100,000 to $199,999, signaling that companies are willing to pay for engineering talent.

Nevertheless, compensation for engineers is rising at uneven rates in different industries, and it often depends on a wide range of other factors like education, title, experience, age, and geographic location, among others.

"Technology is constantly evolving," said one of the engineers who responded to the survey. "Those that can train themselves in a skill that is or will be in high demand will do well."

The vast majority of employers plan to pay out bonuses this year, supplementing engineers' salaries with a median bonus of $2,000 to $2,999. About 21.5% of respondents are in store for $5,000 or more in bonus pay this year.

Lots of factors are at play when it comes to calculating bonuses. Many of the respondents (42.7%) get bonus pay based on their personal performance, while others (45.6%) said that their bonus depends on the company's performance. Still others (19.7%) indicated that they partake in profit sharing. It's relatively rare for engineers to get bonuses for anything else, such as finishing a design, hitting a project milestone, or being awarded a patent.

Only around a third of respondents said they expect stocks to be part of their compensation package this year. About 15% noted their employers offer purchase plans so that they can buy stock at a discount. And approximately 13% of professional engineers are counting on $10,000-plus in stock awards in 2021, according to the survey.

In terms of compensation, about 25% said that it will rise by more than 6% this year—almost double the total in 2021—signaling that companies are raising engineering pay even as the global economic outlook darkens.

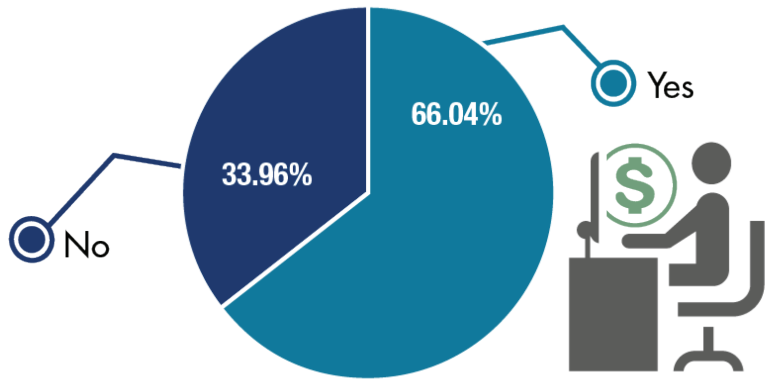
According to the results, around 45% report they will see wage growth of between 1% and 6% in 2022. But as inflation rises rapidly, these paychecks will not go as far as they used to—or as far as they want.

About 22% said their compensation will be unchanged, whether because of economic pressures, business challenges, cost-saving measures, or other factors, such as older workers reaching the top of their pay range or retiring. Only about 8% of engineers said their wages will decrease this year, about the same percentage as last year.

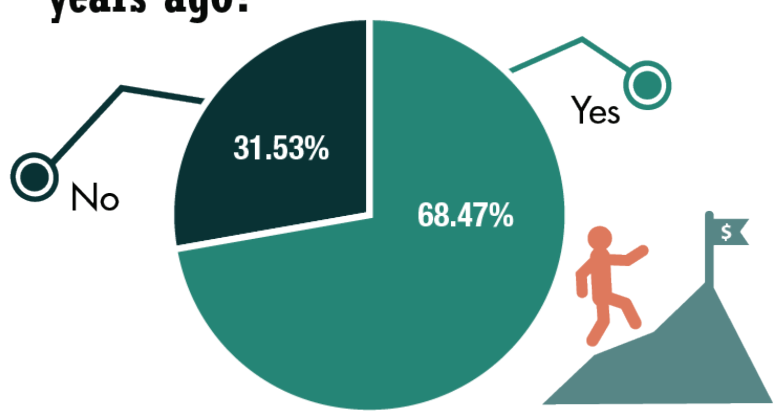
The gains in compensation come as companies confront what they claim is a widening talent shortage. The apparent shortage of engineers—or at least the perception of it—has been worsening for years at this point.

In 2020, 54% of survey respondents said their companies were having hiring troubles. In 2021, the figure soared to

Do you feel your company adequately compensates you for the work you do?



Do you believe that a career path in engineering and the potential for salary advancement is as promising today as it was five years ago?



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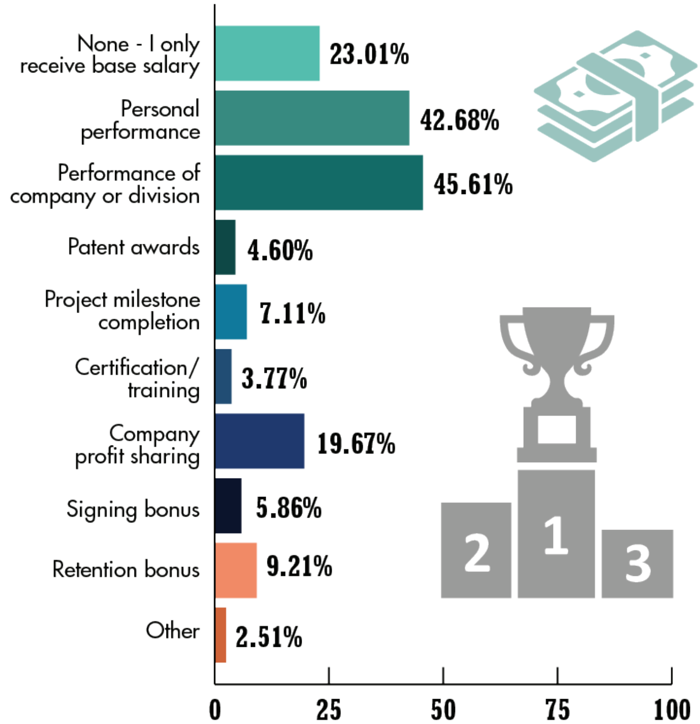
67%. Now, over 76% say they're struggling to find qualified candidates for open positions.

And while many engineers complain that they have to move into management or executive roles to start seeing strong gains in compensation, the shortage of engineering talent is paying off for workers with the skills sought by companies.

As one pointed out, "I think companies are starting to realize they need to pay better to keep their top talent."

"The need for engineers will always be there and, if history proves anything, new fields of engineering will be developed in future generations."

Of the bonuses and other direct cash payments over and above base salary that you receive, please specify the primary reason(s) for them?



Staying Competitive

While many engineers feel as though they deserve to be making more money, around 90% say they would recommend engineering as a career path to young people looking for competitive pay and room for growth.

Said one respondent, "The need for engineers will always be there and, if history proves anything, new fields of engineering will be developed in future generations."

Around two-thirds of engineers say their employers sufficiently compensate them for their work, a slight increase compared to last year. But many can't shake the feeling that the grass is greener on the other side of the electronics industry.

About 36% feel their compensation is as competitive as what other companies are paying for the same job, while only 25% said they're probably better compensated than their peers at other employers.

Over 39% indicated that their compensation is likely less competitive than what other firms are willing to pay this year.

While most respondents said that their companies pay them what they're worth, others feel that they deserve to be making more money—in some cases a lot more. Many think that their salaries are out of step with the level of education that's required for the job, the level of expertise they need to bring to the table, and the increasingly wide range of responsibilities and technologies they must stay on top of to succeed.

Among the one-third of respondents who feel short-changed by employers, more than half believe they're entitled to a raise of 10% to 25%, while around 30% indicate that they should be paid more than 25% over their current salary.

Employers also are increasing non-wage compensation and offering other perks to keep engineers from leaving for other jobs. Many are putting up the money for continuing education, as the engineering shortage pushes them to nurture new skills internally, and even reimbursing for tuition. Some respondents say they're also footing the bill for travel to in-person industry conferences and training courses to keep them up-to-date.

Covering the cost of healthcare continues to be one of the top priorities for employers, according to respondents, and many also are paying for work-from-home-related expenses and resources, including internet.

While electrical engineering can be a grind at times, most professionals said there is room for growth. The potential for salary advancement in engineering, said 68.5% of respondents, is at least as favorable as it was before the pandemic.

As one put it, "Business majors are not going to design these things." ■

DAVID MALINIAK | Senior Editor

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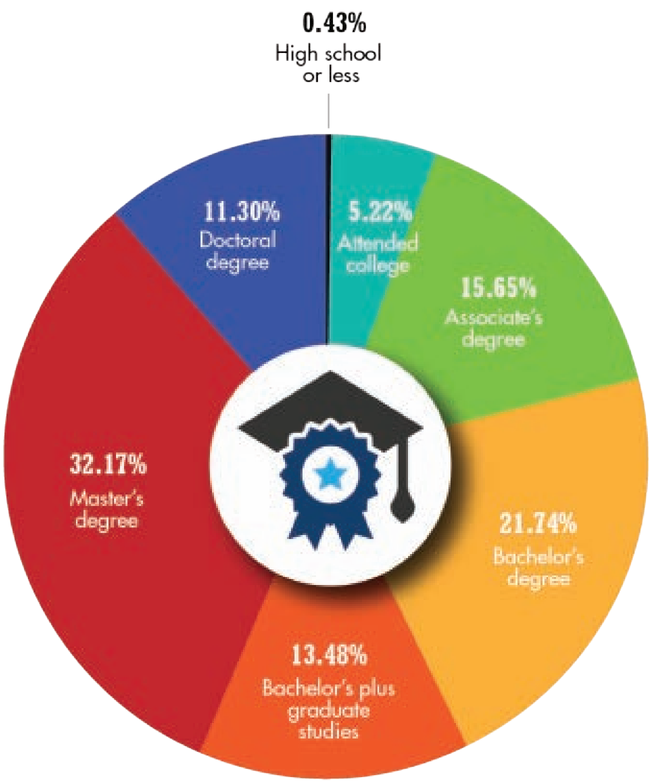
2022 Salary & Career Report: **Continuing Education**

What's the current state of continuing engineering education? Our 2022 Annual Salary and Career Report survey provides a snapshot and hints at some trends.

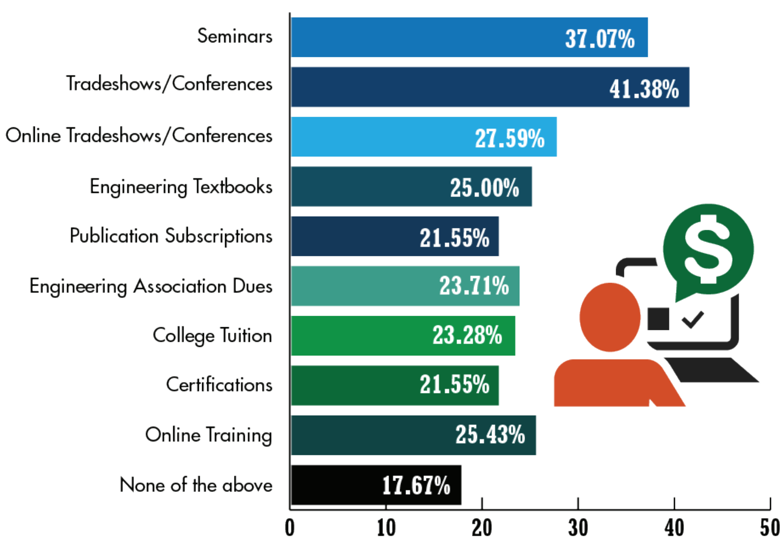
When asked about the biggest challenges in staying current with relevant engineering information, one respondent to our *2022 Salary & Career Report* survey replied, "It's having adequate time to get future-proof design knowledge and the willingness of management to learn, innovate, and invest in technology." That's a representative example of the attitude among engineers about refreshing and/or continuing their engineering educations. There's certainly no shortage of new technologies to stay abreast of, making continuing education a perennial requirement.

In our survey, we asked you to update us on your current level of education and how you prefer to learn about new technologies and skills. Does your employer

Which one of the following best describes your highest level of education?



For which of these forms of education does your company reimburse costs to engineers? (Select all that apply)



encourage continuing education by footing the bill, and if so, in what modes? And how does the coronavirus pandemic figure into the picture? In this article, we'll look at these topics with facts, figures, and anecdotal responses.

Education Levels Declining

First, let's look at where you stand with your respective highest levels of education and see how that compares with the 2021 survey responses. The leading response was a master's degree (32% vs. 46% in 2021), followed by a bachelor's degree (22% vs. 19%). Over 13% claim a bachelor's degree plus some amount of graduate studies. However, at 11%, the number of respondents holding a doctoral degree has dropped from 14% in 2021.

Thus, these survey results suggest that overall, the levels of education among you are declining a bit year on year compared to 2021 at the higher levels of academia.

A Bevy of Educational Options for Engineers

Whether you pursued an engineering career with little or no college-level education or went all the way to a PhD, you still need to keep on top of technology's evolution as you make your way in the industry. So, as we do each year, we asked, "What are some of the ways in which you continue your engineering education?"

The results, as usual, were a mixed bag. Curiously, though, more categories of educational options have fallen off in usage since last year's survey than those that have grown. More than anything other than the anecdotal responses to the survey, this fact points to the time crunch engineers are under in their day-to-day lives.

Vendors to the OEM electronics industry have always done a great job at cranking out videos, white papers, and webcasts to educate engineers on their latest and greatest innovations. All of those mediums are free to consume, and webcasts can usually be viewed on demand if you've missed the live events.

This year's leading category among continuing education options is seminars—

nearly 51% of respondents rely on them for information on new technologies. That's a drop-off from 63% in 2021. About 48% favor white papers (down from 67% in 2021), while 47% like engineering publications (down from 71% last year). Webcasts are down to 42% from 58% last year.

Use of engineering textbooks has fallen way off from 56% in 2021 to just 35% in 2022. And eBook usage also has dropped from 42% last year to 35% this year.

Among the education options, which more respondents say they're looking to in 2022 compared with 2021, are in-classroom college courses (over 14% in 2022 vs. 11% in 2021), online college courses (27% vs. 20%), user group meetings/meetups (20% vs. 17%), engineering association-sponsored meetings (over 23% vs. 17%), and in-person trade shows and conferences (26.4% vs. 26%).

It's interesting that the in-person modes of continuing education—things like in-classroom college courses, user-group meetings, and meetups—comprise most of the education categories seeing more usage this year than last year. Even though COVID-19 is still with us in its various strains, it seems that more engineers are willing to take the risks that come with being out and about and in groups. Hopefully, that trend will continue as we turn the calendar over to 2023 and beyond.

It's About Time

Our survey indicates that fear of contracting disease is no longer the big barrier to continuing education that it was in 2020 and part of last year. Lack of time is what stymies engineers the most. "It's a challenge to find the time to educate myself, improve, and stay current while still performing all my work duties and maintaining work-life balance and supporting my family," said one respondent. Another chimed in with "Too much time is consumed by trivial tasks at work."

As noted above, work-life imbalance is an ever-present issue for engineers, and not everyone wants to take home training materials or extracurricular reading. "Balancing work and life while keeping up with new trends is very difficult," offered one respondent. Indeed, many respondents would rather do it on company time, but it's just not possible: "I have over an hour commute each way, which is time I can't spend studying."

Another oft-cited roadblock is the sheer volume of material to be sifted

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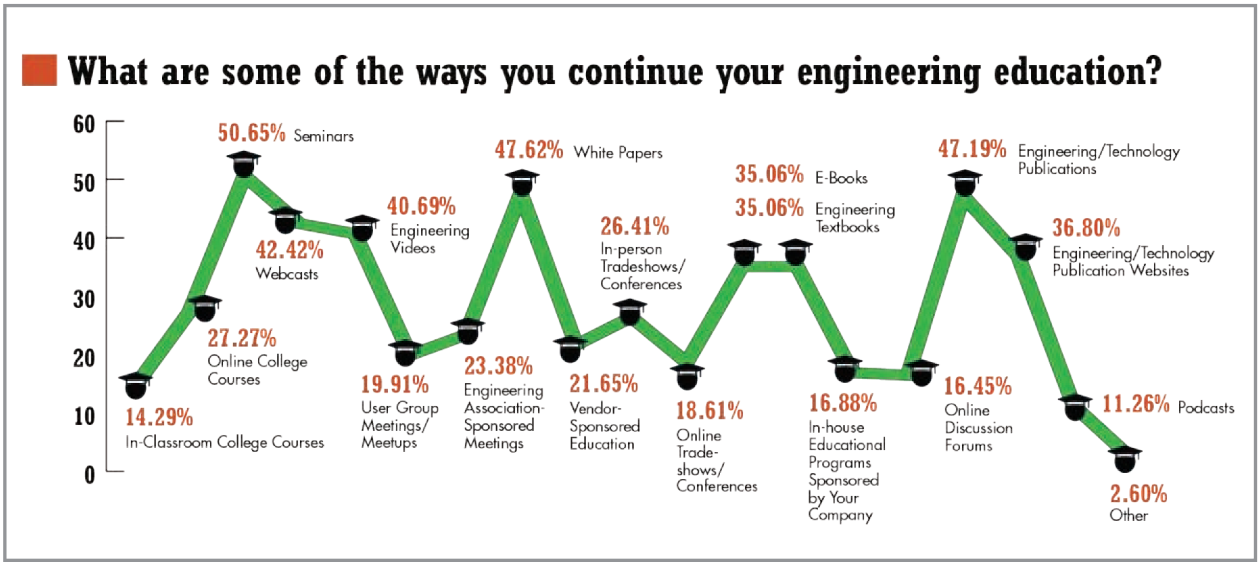

(Continued on page 62)

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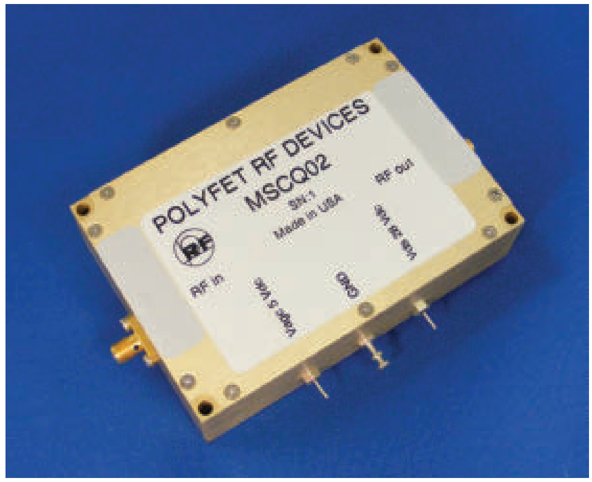
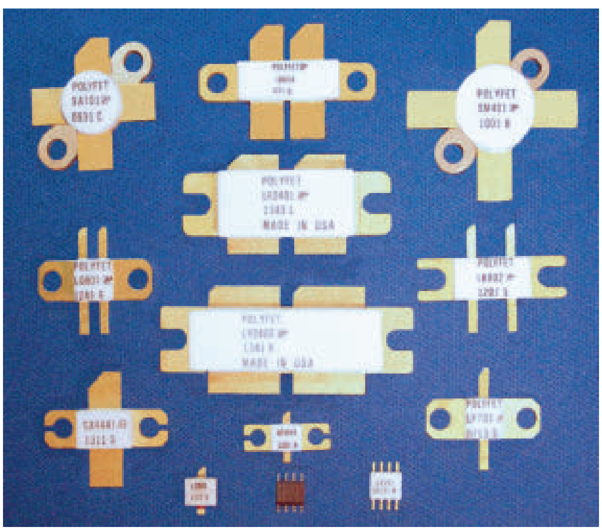
Polyfet RF Devices is an ISO 9001:2015 certified manufacturer of broad band RF power transistors and power modules. We are a private corporation, founded in 1987, and located in Ventura County California. Our product portfolio consists of Gallium Nitride, LDMOS, and VDMOS technologies and are manufactured in the US. In 1995, Polyfet was one of the first companies to develop LDMOS power transistors. Today we are one of the few companies that manufactures devices from a broad range of technologies including both 28VDC and 48VDC RF power GaN transistors. Our technical staff is employed to assist our customers with extensive technical support ranging from device line-up suggestions to amplifier design assistance. Also available to our customers is access to a wide range of product demonstration amplifiers. Our commitment to long-term production support is welcomed by military contractors who use our products where obsolescence is a concern. Furthermore, we manufacture transistors that are proven to be suitable replacements to others in the industry that have seen EOL.





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When it comes to providing discrete transistor or module solutions for RF power applications, Polyfet RF Devices is a company to consider. Given that we manufacture vast lines of transistors and modules, the chances are we have a solution for you. We have a long history of manufacturing these products and continue to develop new ones. Thank you to all our customers for using our products.

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Pulsar's couplers and power dividers couplers range in frequency from DC to 70 GHz. Lumped elements are used for multi-octave requirements from DC to about 3 GHz with power levels up to 2.5 KW to optimize bandwidth and size. Microstrip circuits are used for frequencies from 250-6000 MHz to obtain low loss, moderate bandwidths and power levels up to a few hundred watts, and air-line is used for power levels up to 600 watts. For multi-octave bandwidths up to 70 GHz, strip-line configurations yield optimum performance. So many designs are available that a customer can easily find one that either fits or that we can modify to fit the application.

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PULSAR
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(Continued from page 55)

through and prioritized. "Parsing which technological advances are relevant to my company, and how soon they will be available or reasonably priced, is part of the problem" said one respondent. Meanwhile, another laments that "I cut a large swath from RF to digital to embedded software to CAD. It is hard to stay current across all of it." Still others cite the combination of the pace of change in the industry and the number of topics to keep abreast of.

To be sure, there's no shortage of information to be had. Some respondents mentioned the need to vet information, both in terms of accuracy and its relevance to current projects.

Employer Support is a Mixed Bag

Finally, we asked whether your employer invests in its engineering staff through reimbursement of the costs of continuing education. Our 2021 survey showed a broad downward trend in support for employees. This year, the results have unfortunately declined again in most categories.

First, the good news: Here are some examples of cases in which employers are being more generous. When it comes to the cost of online tradeshows and conferences, 30.5% of employers helped this year vs. 20% last year. They were a bit more generous for engineering textbooks (27% vs. 25.5%) and with engineering association dues (25% vs. 21.5%).

But sadly, in many other modes of education, employers in 2022 are less supportive of their staffs' professional growth. Seminars (33% in 2022 vs. 38% in 2021), in-person tradeshows/conferences (37% vs. 39%), college tuition (26% vs. 31.7%), certifications (23% vs. 29%), and online training (26.6% vs. 32%) have all seen declines in the number of respondents saying their employers helped foot the bill.

Even though employer support is down for many facets of continuing engineering education, only 14.5% of 2022 respondents told us that their employers didn't support continuing education at all. In 2021, 27% said they got no help in any respect. So, overall, it seems that more employers are helping in some way than not at all, and likely in lesser amounts when they do.

Without a doubt, staying on top of technology trends and project-relevant information is a difficult endeavor. Here's hoping you're able to maintain and expand your knowledge base sufficiently in 2023 to keep you at the top of your game. ■

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MICHAEL SEAHOLM | Product Manager, Performance Oscilloscopes, Tektronix

The Need for **Faster Time-to-Insight** Opens the Door for New Test Category

With the increase in demand to meet PCIe specifications, testing and validation tools are paramount for companies and industries to deliver new innovations to market faster than ever.

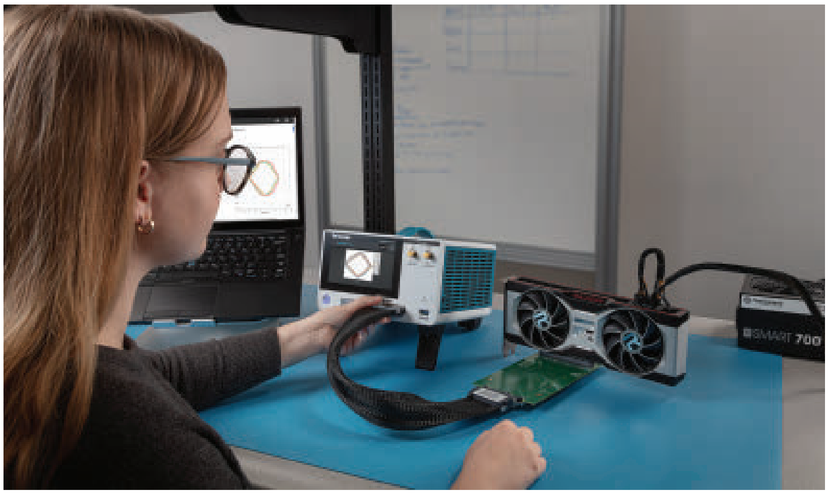
Less than 20 years since the PCI Express (PCIe) 1.0 specification was introduced by the PCI Special Interest Group, the industry is already preparing for PCIe Gen 6.0. With each new generation of the standard doubling the data rate of the previous generation, PCIe Gen 6.0 is more than 25X faster than the original PCIe Gen 1.0 specification introduced in 2003.

This doubling of data rates every three years has introduced countless challenges for validation engineers responsible for the physical-layer performance of their PHYs, chips, cards, and systems. And not all are being fully addressed by testing equipment available today.

While most of these challenges have been addressed by the increasing performance of key electrical validation equipment like oscilloscopes and BERTs, these performance improvements also have impacted testing complexities in setup and equipment usage. In turn, it has contributed to increased testing and debug times for validation teams.

It's a natural progression that test-equipment performance exceeds that of the standard it sets out to validate. However, some of the other challenges faced by engineers aren't being fully addressed with test-equipment performance improvements alone.

Engineers today need tools that complement the performance of existing equipment by providing faster time-to-insight and superior ease-of-use, while not significantly impacting capital budgets for their projects. A case for each of these needs can be made by looking at industry macrotrends.


Tektronix

Time-to-Market Challenges: The Case for Faster Time-to-Insights in PCIe Testing

Because the latest PCIe standards must support all previous PCIe generations, the testing matrix for each new PCIe generation grows exponentially for validation teams. This, coupled with the mounting testing complexities as the standards progress, has significantly increased overall testing times for programs working to implement the latest PCIe standards. What further complicates the situation is the expectation that these teams produce next-generation products in a similar time-to-market window as previous generations.

Evaluating link performance and debugging problems takes longer than ever. Unfortunately, the equipment available today doesn't support engineers in a way that saves them days or weeks of debug and performance evaluation necessary to support these timelines. There will always be a need for high-performance tools like oscilloscopes and BERTs that focus on pushing performance boundaries, but the industry needs a new tool in the tool bag.

The modern engineer needs a new category of test and measurement equipment that's easier to set up and use. It also must deliver faster time-to-insight to allow for more frequent testing during design and validation to identify issues earlier in the development cycle.

Expected Labor Gap: The Case for Ease-of-Use in PCIe Testing

As the digital world becomes more deeply ingrained in everyday life, the demand for semiconductors and semiconductor devices continues to grow exponentially. This parabolic growth has most notably led to major challenges for the industry in terms of supply chain and logistics.

What is less-often discussed, and what may be most concerning, is the expected

(Continued on page 72)

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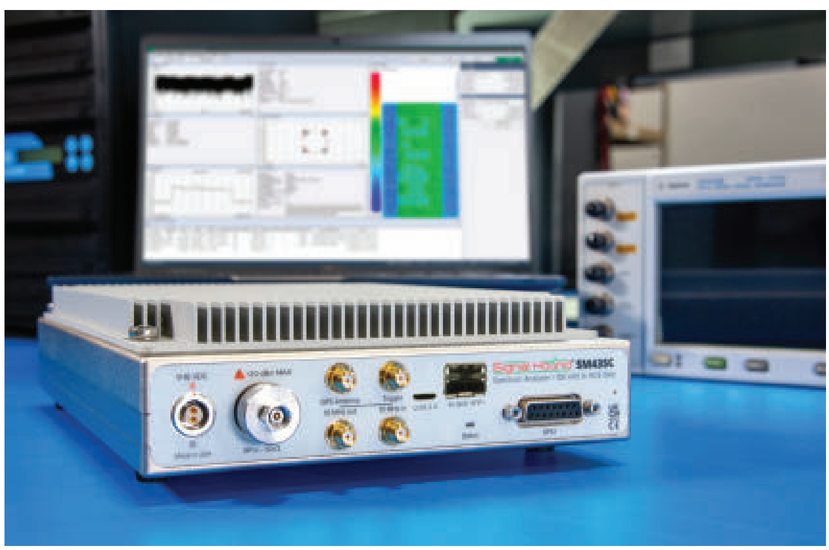
In July 2022, Signal Hound announced the sale of the company to Harrison Osbourn. Osbourn brings a pedigree to his role that includes service as a US Naval Intelligence Officer, time at the Pentagon, an MBA from Harvard Business School, and years of growth strategy implementation with some of the Pacific Northwest's largest and most respected companies. He is a dynamic leader with a proven track record. His vision for the company is informed by the foundational values it was built on and rooted in the vast potential it possesses.

The most recent addition to Signal Hound's product line is the SM435C 43.5 GHz 10GbE Spectrum Analyzer. The SM435C includes a 10 Gigabit Ethernet SFP+ port, enabling long distance PC communication using a fiber optic cable. The Option-80 variant of the device provides downconverter functionality, allowing engineers working with 5G to utilize 800 MHz of continuous real-time data for in-depth analysis. The SM435C Option-80 is also a perfect fit for applications requiring extremely clean phase noise. The affordability of the SM435C opens the door to industry professionals who were previously unable to attain this power in a compact and economic package.

All Signal Hound spectrum analyzers include Spike™, Signal Hound's spectrum analysis software. Spike offers a comprehensive signal visualization environment with powerful RF analysis features. For organizations requiring more flexibility, each Signal Hound analyzer includes an open and configurable API allowing for custom application development.

Accurate and powerful enough for mission-critical RF analysis, priced at a point accessible to most, and supported by well-qualified engineers, Signal Hound devices offer unrivaled value in the test equipment industry.



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5G is transforming our world. Skyworks is at the forefront of this sea of change. We create products and deliver solutions that make 5G work by leveraging our technology leader-ship, broad systems expertise and operational scale to meet the insati-able demand for high-speed, reliable, always-on connectivity.

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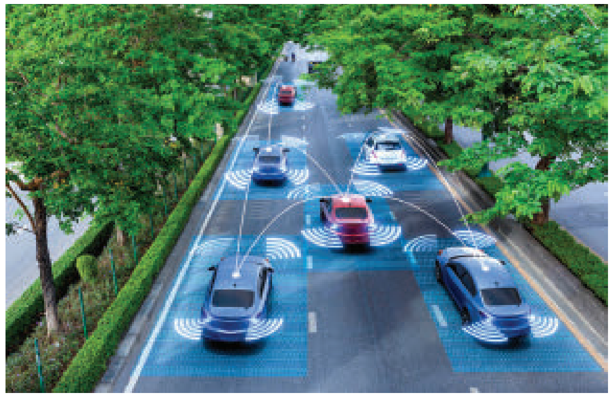

This year's work-, learn-, shop- and play-from-home trends have underscored the importance of our mission of connecting everyone and everything, all the time. While at the same time, there is increasing demand for the speed, capacity, reliability and security that our technologies are uniquely positioned to provide.

Our decades of experience in developing innovative solutions over successive technology generations has positioned Skyworks to capitalize on the robust requirement for data, playing a pivotal role in enabling the connected economy — particularly as each connection becomes more valuable and vital in 5G. From our breakthrough Sky5® unifying platform to our 5G infrastructure solutions, Skyworks' approach across both infrastructure and user equipment facilitates powerful, high-speed end-to-end 5G connectivity.

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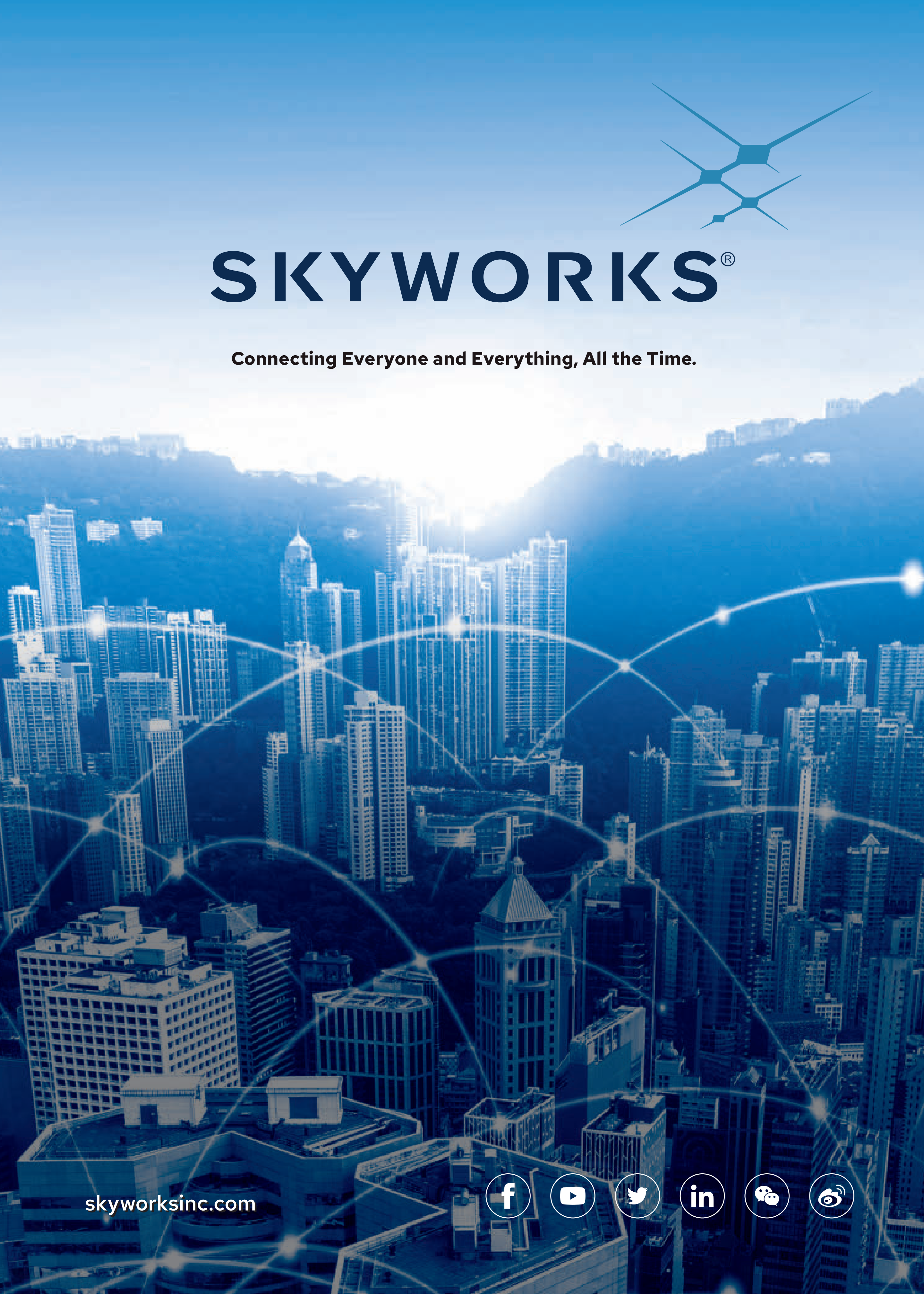
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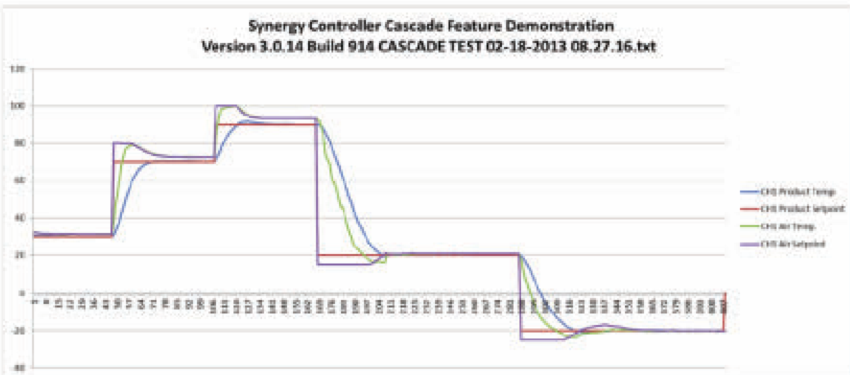
TotalTemp: The New Leader in Microwave & RF Thermal Testing

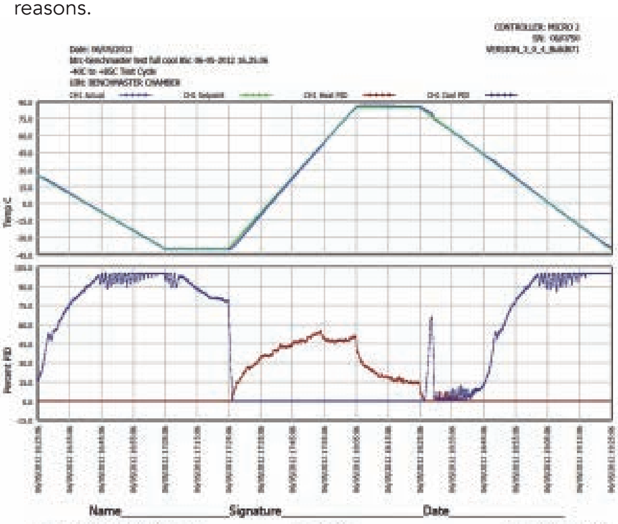
RF and Microwave electronics have had a lot of progress and recent new developments, yet the basics and standards remain.

Similar to RF systems, Thermal Testing has its basic standards and theory. Likewise there are developments in the industry that make a clear distinction between the new modern testing methods available. Convection and Conduction heat transfer basics do not change but we can do a lot to manage the processes better with smarter controllers and multiple sensors. Many devices that need to be thermally tested have sections that are either more thermally isolated, or have varying heat capacities and even active loads. These variables can be quickly monitored and managed using modern temperature control methods.



Temperature controllers that can read and control from two or more points have been around for decades. However, automating the process with multiple sensors has become a lot easier with newer temperature controllers. Additionally, convenient new automation features such as status/alarm reporting can save time and prevent damaged products. Email or text alert can quickly save an automated production test from going into the weeds wasting time and money.

Temperature chambers have been standard faire since environmental testing standards such as MIL-STD-810 were first written. Applications for thermal platforms have found wide and growing usage in the RF & Microwave industry for several reasons.



1. *Fast and easily programmable transitions to temperature.*
2. *Large heating and heat removal capability.*
3. *Easy benchtop accessibility to the device while under test.*
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5. *Reliable wide temperature range with ultra cold temperature capability.*
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Using LN_2 for cooling is very effective and has beauty in the simplicity of only requiring one moving part. Systems using LN_2 are cheaper to buy and operate than complex compressor based systems, especially when counting in the maintenance and electricity costs. TotalTemp is currently working on modern designs to greatly improve the capacity, efficiency and reliability of standard refrigeration based systems using latest technologies for cases where LN_2 is not practical.

TotalTemp has a notable unique offering that delivers the benefits of thermal testing with both conduction and convection together. This advantage, along with the advanced control algorithms has customers reporting that they can cut test time in half. The combined effects of conduction and convection results in both speed plus reduced thermal gradients.

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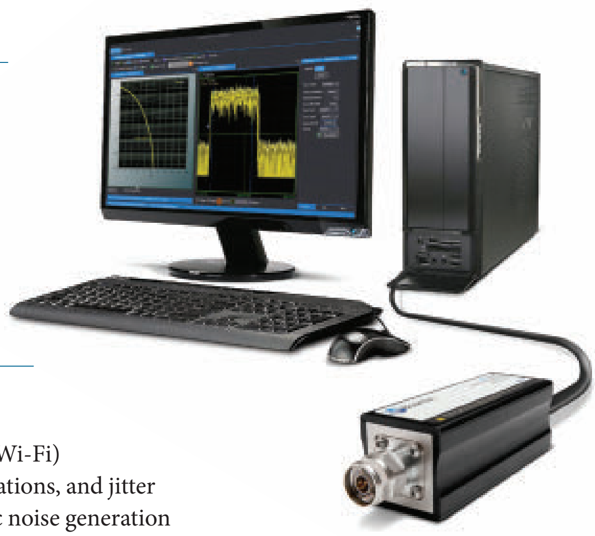
Boonton Electronics is a leader in high-performance RF and microwave test equipment for radar, avionics, electronic warfare, satellite and wireless communications (5G/Wi-Fi), and EMI/EMC applications. The Boonton product portfolio includes peak and average RF power meters, real-time USB RF power sensors, RF signal generators, RF voltmeters, modulation analyzers, and audio analyzers.



NOISECOM

Noisecom is a leading provider of RF and microwave noise sources for signal jamming and impairment, simulation of OFDM (4G/5G/Wi-Fi) modulated signals, calibration of test systems including OTA applications, and jitter injection for digital communication system stress testing. Electronic noise generation devices from Noisecom come in a variety of product types which can be tailored to specific requirements and includes noise diodes, built-in-test modules (BITE), calibrated noise sources, jitter sources, cryogenic noise standards, and programmable instruments.

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Holzworth Instrumentation is a leader in high-performance phase noise analysis and signal generation for test and measurement solutions in government, commercial, and academic environments. Optimized for ultra-low phase noise performance, Holzworth products offer fast switching speeds, excellent spectral purity, high accuracy, and high reliability while meeting stringent performance specifications in a unique form factor. The Holzworth product portfolio includes real-time phase noise analyzers, single and phase coherent multi-channel broadband RF and microwave synthesizers, frequency dividers, amplifiers, downconverters, phase detectors, and phase shifters.

(Continued from page 63)

shortfall in the engineering workforce to support the growth. According to a presentation from the 2022 SEMICON West conference, by 2030 there will be an expected deficit of approximately 300,000 engineers needed to support the growth of the semiconductor industry. This deficit is largely attributed to fewer new college graduates transitioning into the industry and the expected attrition from the ranks over the coming years.

This is a significant complication for companies in the industry, and one that's not easily solved due to the technical nature of development and validation of high-speed I/O (HSIO) devices. PCIe, in particular, is positioned to grow increasingly complex as successive generations of the standards are released. The workforce gap to support development and validation of these devices is expected to put further stress on program timelines and testing workflows for engineering teams across the industry.

To address this expected labor gap across the industry, companies may be required to assign engineering tasks more broadly than in the past, creating a need for testing equipment that's easier to set up and operate than existing solutions. As this macrotrend unfolds, it will become ever-more important to have equipment that requires less training and expertise to operate, yet still provides meaningful insights into the health and performance of HSIO devices.

Monetary Scrutiny: The Case for Capital Budget Optimization in PCIe

As data rates have risen for subsequent standards of PCI Express, so has the demand for higher-performance equipment. The bandwidth requirements needed to support this equipment continues to expand, and with that performance comes significant cost for acquiring full testing suites. These costs are so significant that even larger companies are often in a position to purchase only a few complete systems.

Smaller companies see an even greater impact. They often can't afford the equipment needed for complete validation testing, and instead must rent or use third-party testing facilities to conduct their validation and debug.

Because performance is paramount for full PCIe evaluation and compliance testing, companies must absorb significant equipment costs to perform testing, whether they choose to purchase or rent. While there's no way to avoid this entirely, equipment that can provide meaningful insights into designs earlier and faster without putting significant strain on capital budgets for programs will more readily become a welcome solution.

Having equipment that can accelerate testing by increasing the number of test setups and reducing overall testing times, without putting significant strain on program budgets, prepares engineering teams to efficiently use the higher-performance equipment when needed.

Answering the Call: A New PCIe Test and Measurement Solution

There will always be a need for high-performance validation and compliance testing equipment, but equipment that can accelerate time-to-insight, is easy to use, and is cost-effective, will be a vital complementary solution to the existing tools in the testing workflow for PCIe today. Through the deep understanding of industry needs, the TMT4 Margin Tester developed by Tektronix is the first and only supplemental solution on the market to help address key macrotrends for PCIe Gen 3 and Gen 4 testing. ■

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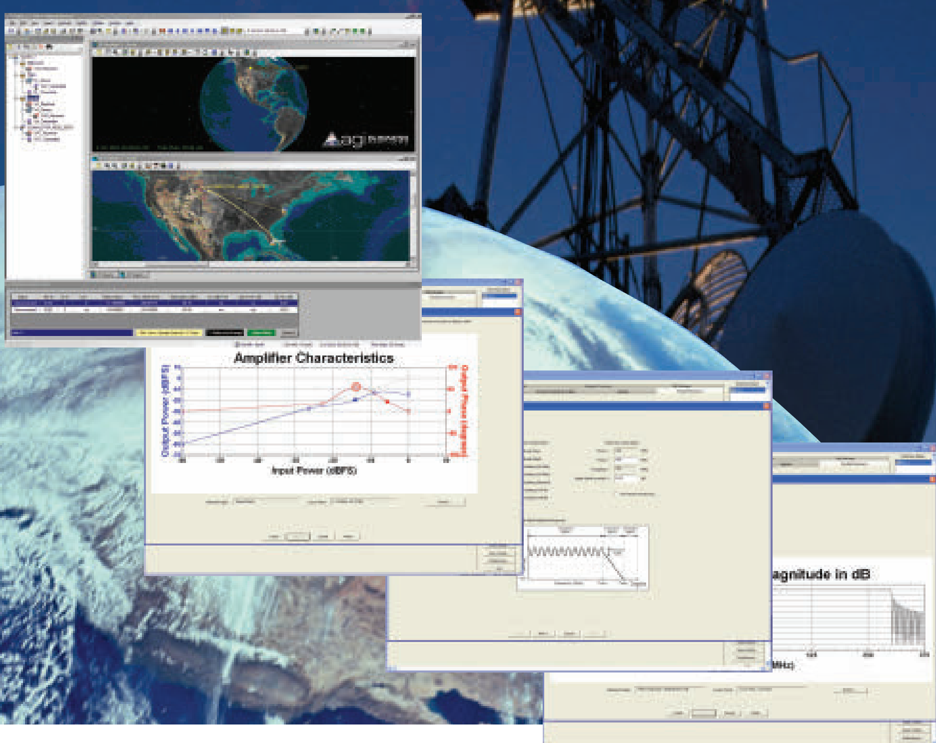

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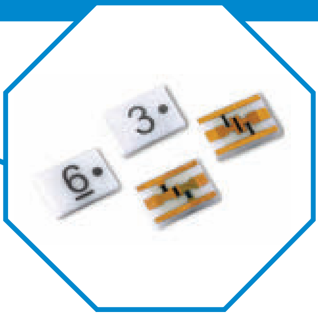
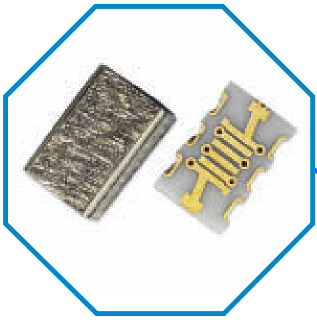
TSX Series - Fixed Chip Attenuators

- Offers excellent broadband performance up to 50 GHz, while delivering increased power handling in a small 0604 surface mount package
- Ideal solutions for pick-and-place and harsh enviroment applications



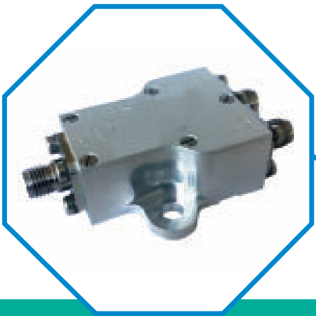


Planar X Series - Thin Film RF Filters

- High performance, compact, light-weight RF filter solutions
- Standard frequency bands of X-Band, Ku-band and Ka-band

SpaceNXT™ QT - Cable Assemblies

- Specifically designed and tested for next generation commercial space applications
- Offered with standardized testing sequences, reducing delivery times and overall cost of ownership



Coaxial Couplers

- Broad range of coaxial couplers for established reliability applications
- Frequency ranging from UHF to Ku-Band supporting a wide array of markets and applications

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